JOURNAL

OF THE

INSTITUTION OF ELECTRICAL ENGINEERS,

INCLUDING

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PUBLISHED UNDER THE SUPERVISION OF THE EDITING COMMITTEE,

AND EDITED BY

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The Institution of Electrical Engineers.

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TABLE OF CONTENTS.

VOL. XXX.

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VOL. XXX. 1900. NO. 147.

An Extraordinary General Meeting of the Institution was held, in association with the American Institute of Electrical Engineers, at 9.30 a.m. on Thursday, August 16th, 1900, in the United States National Pavilion in the Paris Exhibition, Professor John Perry, President of the Institution of Electrical Engineers, and Mr. Carl Hering, President of the American Institute of Electrical Engineers, presiding.

MR. CARL HERING: It gives me great pleasure to open this meeting, the first one held jointly by the Institution of Electrical Engineers and the American Institute of Electrical Engineers.

Such international meetings between societies whose aims are alike but whose surroundings are different, cannot fail to be of interest and benefit to all who take part, and to draw closer together the different nations that participate, thus strengthening the ties which bind together the electrical engineers of different countries.

The promising success of the present session gives us reason to hope that it will soon be followed by other similar international meetings of electrical engineers.

In behalf of the members of the American Institute of Electrical Engineers, I wish to thank you, Mr. President and members of the Institution of Electrical Engineers, for the great pleasure you have given us by joining us in this international gathering. It was quite a venture for us to hold a meeting so far away from home; in fact, when I first suggested it some years ago the proposition met with some ridicule by members of our board of managers. When we found, however, that our older and larger sister society in England joined us so heartily in our proposition, the success of our venture was at once

assured. I feel sure that those of our members who are present, and many who are not, hope that this, our first joint meeting, will be the beginning of a series of similar meetings of our sister societies, and that the next one will be in the home of our Institute.

(Mr. Hering then made a few remarks in French and in German, welcoming the guests from other foreign countries, and expressing the hope that the electrical societies of the leading countries will join in holding similar meetings, the next of which he hoped would be in the United States.)

In accordance with the arrangements of our joint Committee, there will be two presiding officers. Professor Perry, as the senior officer, will conduct the affairs of the meeting, and will now address you.

Professor PERRY, F.R.S.: After a very few words from me we shall commence the discussion. I can only say to the Americans who are now our hosts in this building that their visit to England gave us very great happiness indeed for four days. I think that every Englishman who joined in the parties feels that it did really give us more pleasure than it was possible for our guests to experience.

There are no minutes to be read at the beginning of this meeting because there have been no such meetings in the past, but minutes are being prepared of this discussion, and let us hope that they will be read on a future occasion. In the name of the two Institutions of Electrical Engineers, we welcome you, ladies and gentlemen, to this meeting.

I will now ask M. Mascart to say a few words.

M. E. MASCART: Je dois d'abord adresser à la Société des ingénieurs électriciens de Londres mes très vifs remercements pour l'honneur tout à fait exceptionel qu'elle a bien voulu me faire en me nommant vice président: j'ai été extremement touché de cette marque particulière d'estime, et j'ajouterai d'affection, de la part des membres de cette société.

On a émis tout-à-l'heure la pensée qu'il serait très utile de rendre plus fréquentes les réunions analogues à celle ci, c'est-à-dire des réunions comprenant les membres des sociétés d'électricité des nations les plus importantes; vous avez commencé par donner l'exemple, et nous vous remercions d'avoir réuni à Paris les membres des deux grandes sociétés d'Amerique et d'Angleterre.

Vous nous conviez à aller aux États Unis; je vous assure que ce serait pour moi un très grand plaisir, parceque j'ai conservé un souvenir charmant du voyage que j'y ai fait il y a quelques années, mais je commence à être de ceux qui ne voyagent plus beaucoup. J'espère, néanmoins, que les membres de la société des électriciens, qui se sont déjà préoccupés de cette question, répondront à votre appel et que, bientôt, vous pourrez tenir en Amérique, à Philadelphie, par exemple, une réunion des sociétés des électriciens d'Amérique, d'Angleterre, de France et d'Allemagne sans compter les autres pays.

Mai si je ne puis pas être des votres dans cette circonstance, je vous accompagnerai, cependant, de mes voeux les plus sincères pour le succès de votre réunion.

Maintenant, au nom des électriciens français, au nom de la société des électriciens, je vous remercie de nouveau et très cordialement d'avoir choisi la ville de Paris pour y tenir une séance de vos sociétés associées. Je remercie, en particulier, nos deux honorables présidents qui ont eu l'initiative féconde de cette réunion extra-territoriale.

Professor J. PERRY: I will ask Mr. Ferranti to open the discussion.

DISCUSSION ON THE RELATIVE ADVANTAGES OF ALTERNATING AND CONTINUOUS CURRENT FOR A GENERAL SUPPLY OF ELECTRICITY, ESPECIALLY WITH REGARD TO INTERFERENCE WITH OTHER INTERESTS.

Mr. Ferranti.

Mr. S. Z. DE FERRANTI: I am indeed greatly honoured by being allowed to open the discussion at this most fortunate meeting. I say most fortunate, because you will all agree with me that nothing could be better than that the American and English Associations of Electrical Engineers should have a joint meeting. There is only one thing in my mind which is perhaps better, and that is that we should be holding this meeting in Paris, and thus show what a great tie really unites us all, and how much more friendly our feelings really are than is often supposed. The subject for this discussion was left for the English Institution to select, and I can assure you, gentlemen, that it was a matter of no little difficulty to decide upon what we should discuss. The subject which has been chosen you may at first think is simply a revival of the old contention between alternating and continuous current. I hope, however, that it is no such thing. Matters have greatly changed since the early days when the advocates of each of the two systems were, I may almost say, bitter enemies, and when they thought that everything that was done by the other side was

Mr. Ferranti.

wrongly done. We have all found that that is not so, and that there are great merits in the particular uses of both systems. But, as I have said, things have changed, and they have not changed yet as much as they are going to change in the future. The question that we have to deal with must be considered in the light of what electricity will be ten, fifteen, or twenty years hence. You have seen how the industry has grown; you know, by being members of the electrical profession, how much it has done up to now. I think few of us, although it is our life's work, realise what electricity is going to grow to, and how important and universal a part it is going to play. It is, however, in this light that we must consider what are the best lines to be worked upon. It is no longer the small isolated systems which could be worked on one plan or another according to convenience; that we have to deal with, but it is the question of transmitting and using big powers all over large areas. Now, with regard to the advisability or desirability of one system, the continuous as against the alternating current: many of you know that I have consistently worked with alternating currents, and you will therefore appreciate that my knowledge of the other subject is not what it should be as compared with that of those who have worked more exclusively in that direction. I, however, desire to dissociate what I have done from what I am going to say, and rather than give so much my own opinion, I shall suggest a few points to you bearing upon what the general opinion is on this subject, as I consider it most important.

Looked at from the new point of view, this is what presents itself: Which will be the possible system in the future? I say "possible" because many of us have had very serious experiences of the electrolytic effects which are produced to such a large extent by the continuous current. What I am wondering is this: If this system is developed and extended to a very large extent, will it be possible satisfactorily to preserve any metal work in the earth at all? We have not only got to deal with the lead coverings of electric cables, but we have also any amount of structural ironwork—water mains, railway rails, gas pipes, water pipes, and all sorts of things—the quantity of which is increasing every day in our streets all over the country. The amount of property invested underground in one or other of these forms is reaching a very great figure; and it becomes a serious question for us, not so much in the light of to-day, but in the light of the future, when immense developments will have taken place, to know on what lines we should go, and how best to protect this immense property, which may be injured by the otherwise beneficial work which we are doing. Of course alternating currents are not quite free from the liability to produce some harm, but what little harm they can do is not of commercial importance. Therefore I consider it will want our most careful thought and work and investigation to find out really how we can diminish these electrolytic troubles, due to continuous currents, or whether it will not be necessary to substitute alternating current, which produces but slight detrimental effects, and see how to overcome what disadvantages are now left to it. I hope that a great many of you gentlemen present will give us valuable information on this subject, and, after you have left this meeting, having

heard the discussions which have taken place, that during the next few years you will give the matter your careful consideration, and then contribute your views through the electrical press, or by another such meeting as this, to the electrical profession at large. Mr. Ferranti.

Again, gentlemen, I must thank you for having been allowed to open this discussion. I hope it will be a full discussion and that what I have said may stimulate discussion and lead to careful consideration of the subject which will prove beneficial to the electrical industry in the years to come.

Mr. BION J. ARNOLD: I wish to express my appreciation of the honour conferred upon me by being permitted, in this discussion, to follow so distinguished a worker in the electrical field as Mr. Ferranti. I did not know about my colleagues' intentions of calling on me this morning until late last evening, otherwise I would have taken time to prepare my remarks. We have all heard that the man who dares to assert that "electricity is in its infancy" is liable to annihilation on the spot; but after Mr. Ferranti's remarks I fancy we may be considered, for the moment at least, to be on the threshold after all. Mr. Arnold.

I think it may bring out the discussion of this subject between the different countries, here represented, more thoroughly if I outline briefly the practice in the country which I come from, viz., the United States of America. For lighting work we started in our large cities with the direct current system as advocated by Mr. Edison. By the way, I once saw a letter from Mr. Edison, written some ten years ago, in response to an inquiry addressed to him asking his views on the relative advantages and disadvantages of the alternating and direct current. His letter intimated that he thought the alternating current was of Satanic origin, that it was a delusion and a snare, and that no good could come out of it. Mr. Ferranti has proven that the contrary is the case, and judging from his remarks and the work of many others it seems as though the ideas of his Satanic Majesty may yet prevail.

Returning to our subject, we started in our large cities with the direct current system and in our smaller cities with the alternating system, To-day the direct current seems to have not only held its own in our large cities, but, in addition, is replacing the alternating system in some cases, although the alternating system holds its place for smaller cities covering widely distributed districts and for transmission to the outlying districts of our larger cities. In the City of Providence, Rhode Island, one of the first and leading cities in the electric lighting industry, the alternating apparatus originally installed has been entirely thrown out, in the underground districts, and replaced with a direct current system of supply, delivering energy on a three-wire 480–240 volt system. The same thing is taking place in the City of Saint Louis, Mo., although at this point they have not abandoned the use of the alternating apparatus, but a competing company has installed a direct current system on the 480–240 volt three-wire system, which company has largely taken the business of the alternating company within the district it reaches, and the net earnings and operation of the direct current company have been very satisfactory. I mention these two important installations to emphasise my statement that the direct

Mr. Arnold.

current is holding its own in our larger cities. I believe the alternating current will hold its prestige in our smaller cities and in the outlying districts of our larger cities.

In answer to Mr. Ferranti's advocation of the alternating current for lighting work in large cities, I will say that there are no means, so far as I know, for equalising the load upon the power station when the alternating current is used, thus losing the advantages gained in direct current work when using storage batteries. The installation in the latter case would require less investment than would be necessary if the alternating current were used, assuming a reasonable area over which the energy is to be distributed.

Coming now to railroad work, we started with a 500-volt direct current system, and gradually increased to 600 and 700 volts, and are now utilising the latter on the sections of the roads contiguous to the power houses, and driving our more distant sections with three-phase 25 or 30 cycle alternating current. I believe this will be modified, and that the alternating current will ultimately predominate in railway work. I believe that we shall soon eliminate entirely the sub-station, the rotary converter, and possibly the static transformers at the power house. We shall at least eliminate the sub-stations. Mr. Ferranti is no doubt working on this theory, and so also are others, in the respective countries here represented, including some from the United States. Some of us feel that there is a fair hope for success. It may, of course, be slow in coming, but that it will come I have no doubt. There are two main difficulties at present in the way of a complete and successful alternating current railroad system. The first is the lack of a practical method of starting and controlling the speed of an alternating motor without excessive consumption of energy. The second is the one pointed out by me when referring to lighting work, viz., the lack of a load equaliser corresponding to a battery in direct current work. Some of us are hoping for and endeavouring to develop a system by means of which we will utilise or have the advantages of an equalising reservoir as it were, thereby taking the place of the storage battery in direct current railway work. I believe this is coming, and if it is successful we shall have an ideal system for long-distance railway work, utilising all the advantages of the alternating current for transmission and the advantages of the equalised load factor for economy, and we shall not have the disadvantages of the sub-station and its corresponding maintenance and labour expense.

I do not know that I can add anything more to the discussion, but if I have succeeded in pointing out, in a general way, the lines upon which the engineers of our country, and possibly of others, are working in the lighting and railway fields, it is all I can reasonably hope to do in the time allotted to me. If any further information is desired regarding the details of the work to which I have alluded, I will, if the questions are asked, give such information as I can consistently at the present time.

Sir William Preece.

Sir WILLIAM PREECE: I feel somewhat in the same position as the blank leaf between the Old and the New Testament. I am here as a past

President of the British Institution of Electrical Engineers, but I am also an Honorary Member of the Institute of Electrical Engineers of America. I therefore speak in the blank-page capacity. I also hold the position of never having compromised myself by associating myself either with the direct current or with the alternating current system. I have used both when I thought either was right. I believe there are circumstances in which the one is essential, and under different circumstances, where the other properly comes in. Sir William Preece.

Now, we want to consider the subject before us from different points of view. We have to consider generation, we have to consider the distribution of our currents, and we have to consider the transmission of these currents to great distances. In the first place we have to deal with the generation of our currents, and there we start exactly from the same point, for we must all remember that an ordinary dynamo is nothing more nor less than a simple alternator. So we start from the same basis.

Mr. Ferranti commenced his remarks by referring to some of the disturbances. He dealt with the electrolytic effect upon pipes and metallic coatings. There is another serious disturbance that has caused many of us anxious moments, and that is the disturbance produced by alternating currents upon telephones. I have always said that the telephone is perfectly competent to take care of itself. The alternating current engineer need not worry himself about telephones. The telephone is never complete until it has worked on metallic circuit, and when that metallic circuit is tested and properly maintained, no alternating currents, whatever their frequency, whatever their strength may be, can possibly affect telephones. There is another serious difficulty that we have met with in our practice, and that is disturbances to railway signals. Although under ordinary normal conditions alternating currents cannot affect the railway signals, there may be sudden rushes to earth due to those strange effects that were once called, and rightly called, Ferranti effects, certain sudden effects of momentum in alternating circuits which raise the voltage so that the insulation is pierced by great surgings of current. Such things have produced, and will produce, false signals on our block system unless some step is taken to prevent them.

The rest of the disturbances are comparatively trifling in their frequency; but they have been serious in their consequences. There are the fires that have been caused by some of these surging effects to which I have alluded. Now, in determining the necessity for the use of either system, we have not only to consider what I have said, but we have to consider the use to which it is placed. There is first electric lighting, next motive power, thirdly traction, and fourthly the transmission of power to a distance. I do not think there is a single man in this room who would not agree that the only practical and the only possible way to transmit energy to a great distance is now the triphase alternating current system. No high pressure continuous machine has yet been constructed which could possibly do what is being done between Niagara and Buffalo and in California and in Switzerland. There can be no question that for transmission the alternating currents must be considered pre-eminent.

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Sir William Preece.

As regards motive power, we come to quite another question. There is no doubt at the present moment that the triphase motor is as good as, if not better than, the continuous current motor under some circumstances. Mr. Arnold referred to the fact that in his country the continuous current was holding its own and displacing the alternating current. Here in France—I forget where at the present moment—there is an illustration, where continuous current machines have been removed, and replaced by triphase, in consequence of the superiority of the triphase over the alternating current. So we have this curious see-saw going on; at this side of the water the triphase supplanting the continuous current, on the other side the continuous current supplanting the triphase. The moral is, that each in its own sphere is good, and as both are used there can be no serious defects in either the one or the other.

One of the most important questions which has not been raised, and which I should wish to raise, is that relating to the necessity of standardising the frequency. I cannot perhaps remember all the cases, but we commence with Niagara. There the frequency is 25. There is another large installation where it is 45. In many places in England—and Mr. Ferranti himself has started one in the south of London—the frequency is 50. At Deptford, in an installation which he originated, the number is now 67. We come to the City of London, where I think it is 97 or probably 100. In our first alternating current systems in London we started at Sardinia Street with 130. Now we find that the frequency is varying in different parts of the world from 25 to 130, and that shows that there is something wrong somewhere. I believe I am right in saying that the American Engineers would have the standard for motive power 25, for ordinary distribution 50, and for house distribution where each house has its separate transformers, 100. I think that is so, but I have no notes by me to refer to. Anyway, I want to point out that if this joint meeting can possibly do any good it will first allay the impression that there is any difference among engineers as to the relative superiority of alternating and direct current systems; and secondly that now at this joint meeting we might determine a standard frequency that shall apply to various cases.

I have only one more point to make. That is to call attention to one line of progress along which we are working in England. I refer to the distribution of these triphase currents at high pressures to great distances by means of underground cables. Nearly all the experience in America is with overhead wires. The longest underground system which I know is the one established by Mr. Ferranti between Deptford and Trafalgar Square. This is nearly eight miles long. But underground mains to conduct high pressure triphase currents will be laid to a very large extent, and those engineers who will have the designing and manipulation of these must find out and learn all they can of the effects of capacity, for in all I have read and all I have seen that capacity is practically ignored. Everybody considers induction, which is small in its effects compared with capacity. I anticipate, when we get long lines of twenty or thirty miles transmitting triphase currents at

10,000 volts, great difficulties will be experienced in effects due to capacity. Sir William Preece.

Dr. A. E. KENNELLY: The occasion which presents itself to-day for the discussion of this subject is, as we have just heard from Sir William Preece, a most fortunate one, namely, for the expression of opinion as to the best frequency which can be adopted for alternating current systems as well as for the cure or dispersal of some of the mists which still hang over the precincts of the fields of alternating current and direct current supply. I think we are generally agreed, not only in America but also, I think, here and in Europe as a whole, that where you have a densely crowded area to be lit by incandescent lights or arc lights you cannot do better than supply that area with direct current at the pressure at which it is to be operated; and if the area is narrow and constricted you need not exceed the pressure of a single incandescent lamp, or say about 100 volts. But as the area extends, the quantity of copper you put down becomes so large an item of the capitalisation, that you must employ a greater pressure, say 240 or 250 volts, over a distance up to half a mile or a mile. When you come to a greater radius of transmission in your dense area you must employ 500 volts, and finally there arises a limit beyond which it becomes uncommercial to supply the direct current for the direct application and you must introduce a higher pressure. To introduce this higher pressure you must resort to alternating currents, and so in many of the large cities of America you will find that the heart of the city is supplied by a direct-current system on the three-wire plan, and then the outlying regions of that same system are supplied through the medium of alternating currents at higher pressures. The pressure increases as the distance of transmission increases. We are all agreed that when the distance of transmission is considerable you must employ the alternating current. On that ground we all stand. Thus when you have to supply electric traction systems at a distance, you inevitably employ the alternating current, and then you resort at the distant end, at least in America, to the direct-current supply through the medium of converters. The connection together of those two systems is accomplished with difficulty as well as at considerable expense. There is a set of transformers to reduce the pressure, and then there is rotating machinery required to supply the direct current. This condition of affairs is so anomalous and inconsistent with the otherwise great simplicity of electric current supply, that it is difficult to understand how so remarkable a combination arose. I think it may be claimed to be due to the fact that the electric motor for tramways came into existence gradually and developed as part of a direct-current system, and that up to the present time the standard traction systems of America have been all direct-current systems. The difficulty of supplying all the apparatus needed upon an alternating-current basis, even supposing there were no objections and difficulties to be met with in the alternating-current motor, have constituted reasons sufficient to account for the anomalous condition of affairs. If, however, in the future the difficulties which remain in the way of introducing induction-motor street-cars can be cleared away, we may expect, as I think Mr. Arnold intimated, that this condition will be Dr. Kennelly.

Dr. Kennelly.

eliminated, and we shall have nothing more than a plain alternating-current system from beginning to end. The only considerable disadvantage would lie in the difficulty in maintaining a steady distribution of pressure. The difficulty which is encountered in the matter of the distribution of direct currents on electric railroad systems supplied from a distance is, as we know, the electrolytic difficulty. There has been much trouble in America on this account. Many pipes have been destroyed and others have been much damaged by this means. But that difficulty is giving way to careful and deliberate engineering, and it is a much less serious difficulty at the present time than in the past, because engineers know better now what to do. The damage has occurred not so much to large mains as to service pipes crossing the streets, and also to telephone cables where the metallic sheathing is continuous. By careful attention to these conditions, by studying the outlines of the system carefully, this electrolytic difficulty has been, and can be in the future, largely eliminated in maintaining a difference of potential between pipes and tracks not exceeding one volt within the danger area, by putting down a sufficient amount of ground-return copper, and by carefully bonding the tracks. This danger from the electrolytic action resulting in corrosion can be largely eliminated, and we may expect by engineering skill that this trouble will be almost entirely overcome.

One disadvantage, however, which has not been pointed out by preceding speakers in the direction of alternating current traction consists, I think, in the increased hazard from shock and increased danger to life and person. An accidental shock from 500 volts of direct current is not, as a rule, a serious thing. There are cases on record, I believe, where it has proved fatal, but they are certainly very rare, and the number of shocks which are accidentally encountered from day to day over a large number of traction systems is considerable. If, on the other hand, you employ 500 volts of alternating current and get an accidental shock from that, the shock may be much more severe because it would seem from recent experimental researches that the danger from shock is the danger of disorganising the action of the heart. The danger in a shock from the direct current is in the first impulse, and may be recovered from; whereas with the alternating current you get a succession of shocks which may be sufficient to disorganise the heart beyond all chance of restoration.

There are, of course, other outstanding difficulties with alternating current transmission on railroads, but they are all seemingly of minor consequence. There is, for instance, the disturbance affecting the magnetic needle in general and those of a magnetic observatory in particular. But it seems to me that the worst that can happen in that case is the banishment of the magnetic observatory from the vicinity of civilised communities to the more desert regions of the earth. While that may be a misfortune and an expense in particular cases, yet the aggregate advantage to the entire community of giving a traction system on the one hand, and removing an observatory on the other, does not appear to be worthy of comparison.

Professor Ayrton.

Professor W. E. AYRTON: The special point to be decided at this discussion, as Mr. Ferranti brought out, is the relative advantage of the alternating and continous current, especially with regard to interference with other interests. Interference is the main question we have before us in accordance with the title. There is no question whatever that we have had in various countries a very large amount of interference, and therefore I need not go into the details. Electrolytic interference Dr. Kennelly has referred to, as well as others, also telephone interference. A very serious kind of interference has grown up within the last two or three years, namely, interference with submarine cables. A very serious case happened in the Cape of Good Hope, where a large amount of damage was done, and there was considerable stoppage of messages coming by the Western cable to Europe. There has been interference with the magnetic observatories that Dr. Kennelly mentioned at the end of his remarks. There is no question about these interferences, but there is the question how are we deal with them? Should you endeavour to destroy the attack, or should you allow the attack to remain and endeavour to improve the defence? Those are two totally different methods of dealing with the subject. In other words, should you endeavour to construct each undertaking in such a way that it will not cause any interference with anybody else, or will you start with assuming that there is war? Are we to assume that the other side are sure to attack us and that they will not mind our losses and griefs, and all that we can do is to try to defend ourselves? To a certain extent both practices, both plans, have been followed, in Great Britain at any rate. The Board of Trade regulations state that there shall not be more than seven volts difference of potential between any two points of the rails if the rails of the tramway are used as a return. That is an indication of an endeavour to prevent the enemy attacking us too much, allowing them to fire at us but not with expanding bullets, so to say. The regulation does not say how long the line may be with such a restriction, whether it is to be a long one or a short one. Still the seven-volt rule applies. Now, it has been shown conclusively that the seven-volt rule does not give sufficient protection. It certainly does not give sufficient protection in the case of a submarine cable which lands anywhere near the place where the tramway runs. It does not give sufficient protection in many cases as regards electrolysis, and obviously it would not give sufficient protection in any magnetic observatory which might be located in the neighbourhood of the tramway. In the case of telephones it is possible to obtain a very good defence, and to make the telephone people more or less independent of attack. It was indeed the ease with which that defence can be constructed that led the Joint-Committee of the House of Commons and the House of Lords, before whom this matter was brought a few years ago, not to interpose restrictions in the construction of tramways, because the conclusion they came to from the evidence they heard was that a telephone system in Great Britain was so shockingly bad in consequence of the use of the earth as a return—there was in fact so much interference of one line with another—that even if there were no electric tramways at all, and no distribution of electrical energy on a large scale, it would be neces-

Professor Ayrton.

sary for the telephone companies to resort to modifications. They would have to do that apart from electrical distribution, and therefore it was not necessary to restrict electrical distribution because telephones had to adopt their own defence. But regarding the water pipes and gas pipes that does not apply at all. They cannot use anything in the nature of an insulated "return" which will prevent electrolysis.

Now I come to a very important point which has not been suggested by any of the speakers so far—though perhaps I am wrong in saying it was not suggested, as it was implied by Mr. Ferranti—viz., that it would be very different if direct currents were used instead of alternating. But any doubt of the truth of that assertion has not been suggested by any of the speakers. If we were to adopt universally a general system of alternating currents, should we be free from electrolysis? This is a point which has been interesting me for some time past, and I was making some observations on that subject this year in Geneva, where they have suffered a great deal from damage in the pipes. The matter was referred to me to investigate, and I will only remark that it is not at all clear that if only alternating currents were employed the pipes would be free from electrolysis. Some years ago I carried out experiments and showed an interesting one to certain people in my laboratory. I took an ordinary sulphuric acid voltameter, the Hoffmann voltameter, with two tubes and a platinum electrode in each tube. The hydrogen was evolved in one tube and the oxygen along the other. We sent an alternating current through, and the same thing occurred as with a direct current, namely, the hydrogen came off in one tube twice as fast as the oxygen in the other. It is clear that we cannot assume that there will be no electrolysis because an alternating current is employed, and I find on this table a sample, of which I did not know previously, which has been sent by Mr. Trotter, of the Board of Trade, illustrating that very thing. The label says, "One of a pair of lead pipes buried in a box of earth corroded by one ampere alternating current passing from pipe to pipe for six weeks." That is the result. That is not unlike the corroding seen in Geneva during my investigations. Mr. Trotter mentions in his letter that the specimen was corroded by an alternating current coming from Deptford. That does not mean that the Deptford current is worse than any other. He states that the current came from Deptford to show that it was not any fancy laboratory current. I admit mine was a laboratory current, but it was produced at any rate by a Ferranti dynamo. The letter proceeds "to show it was no fancy laboratory current—I add it with regret because Mr. Ferranti will argue, I suppose, that less damage is done by alternating than by continuous current. There are no more particulars to give except that the pipes are six inches apart and the sides where the currents passed each other are more corroded than the other parts."

It is clear, then, that alternating current will not give us protection with certainty, and it is clear also that it is a very important question to examine under what circumstances do alternating currents produce electrolysis, and under what circumstances they do not. That is a subject which has attracted a good deal of attention subsequently to my publishing the little experiment I told you about in connection with the

voltameter, and I shall be very glad to hear from the meeting the results of any experiments which will enable us to settle what should be done with a lead pipe so as to make it, if possible, immune to action by an alternating electric current. For it is not possible to do that if such action occurs. If I polarize my platinum plates by means of a direct current first, then decomposition by means of alternating current takes place with perfect ease. I do not mean to say that the same amount of gas came off for a given number of coulombs which would have come off with the same number of coulombs of direct current, but I mean that when the observer saw the voltameter without looking at the ammeter at all, he saw no difference whatever between the hydrogen and the oxygen coming off with the alternating current as compared with that from the two separate tubes with the direct current. Professor Ayrton.

Speaking now about the defence, about arranging our pipes (water and gas), and the submarine cables, so as to prevent the attack hurting us. In spite of what Dr. Kennelly said, I think more might be done to avoid the attack, and I am happy to say the London Tramways Companies have not looked at the matter at all from the drastic point of view that Dr. Kennelly has just suggested. The London Tramway Companies have *not* said, "We are coming. You have magnetic observatories near London. If we destroy them we are very sorry, and you had better go somewhere else." They have not taken that line at all. The line they have taken is, "Will you try and find out for us what we must do, the least we must do, to ensure you immunity from disturbance?" The result, as some of you know, has been that a Joint Committee was appointed by the Board of Trade to carry out experiments and find out what was the magnetic disturbance produced by existing electric railways and tramways in Great Britain, when those tramways or railways worked under the Board of Trade regulations. When the difference of potential between the rails did not exceed seven volts, what was the disturbance? We found the magnetic disturbance very considerable and the seven-volts limit was quite impossible in the neighbourhood of the observatory.

Without giving you a long account of all the experiments, I will give you practically the final result. The final result of the experiments and negotiations, for which we have very much to thank our British President and Professor Rücker, for they have taken a very active part in connection with these negotiations, has been this: Within two miles of the observatory the Tramway Companies offer to cut up their line into one-mile sections—that is to say, no part of the line in that neighbourhood shall be electrically continuous for more than a mile, each mile being insulated electrically from the rest of the tramway system, and that current shall be brought to the trolley wire at the middle, and taken away from the rails at the middle of each mile section. Further, that no point whatever of the rails of any of these sections shall be allowed to differ from the potential of the earth by more than *one-fifth of a volt.* We have assured ourselves by calculation and by experiment carried out in different parts of London and Great Britain, that with such a difference of potential magnetic instruments will pro-

Professor Ayrton.

sary for the telephone companies to resort to modifications. They would have to do that apart from electrical distribution, and therefore it was not necessary to restrict electrical distribution because telephones had to adopt their own defence. But regarding the water pipes and gas pipes that does not apply at all. They cannot use anything in the nature of an insulated "return" which will prevent electrolysis.

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Professor Ayrton.

bably not be disturbed to an amount that will be practically serious; that is to say, by an amount that will interfere with the ordinary observations carried out in a good magnetic laboratory. So I am very happy to say that the tramways, although they are about to use American plant, have looked at the matter from what I may call in this case a *non*-American point of view. And instead of relying on a supposed superior importance possessed by tramways over a study of the earth's magnetism, they have worked cordially with the Government representatives in ascertaining what precautions must be taken to ensure immunity for the London magnetic observatories without introducing too much interference with the commercial working of the tramways.

There is one other point with reference to alternating currents for electric tramways which has not been yet suggested. I was informed that one of the reasons why in the United States alternating currents were not employed was because they found a difficulty in getting a good contact between a trolley pole and the wire when the wire had snow upon it, more difficulty, that is to say, with alternating than with direct current. Since that time, which was in 1897, certain electric railways have been constructed on the Continent of Europe which use alternating current, and it will be interesting if any one here can tell us whether any difficulty has been experienced in the winter when snow rested on the trolley wire; that is to say, more difficulty than would have been experienced had the direct current been employed.

M. Korda.

M. Désiré Korda: Lorsqu'il s'agit d'une distribution dans une grande ville, le courant alternatif, monophasé ou triphasé, grâce à la facilité de sa transformation, offre des avantages sur le courant continu à haute tension qui exige pour sa transformation des transformateurs rotatifs; quant au courant monophasé, la grande objection qui s'oppose souvent à son adoption est la difficulté de son application à la force motrice, le vrai moteur à courant alternatif simple n'étant pas encore inventé. Par suite, dans bien des cas, on préfère adopter le courant polyphasé malgré la difficulté qu'il y a à régler convenablement les trois ponts, et à maintenir les tensions égales; on a quelquefois recours à des systèmes plus ou moins compliqués, polycycliques ou autres.

C'est sur la question des courants polyphasés que je voudrais dire quelques mots, ou plutôt sur un cas dans lequel leurs avantages et leurs inconvénients par rapport au courant continu se montrent d'une façon beaucoup plus évidente, sur le cas de la distribution de force dans une grand usine, comme, par exemple, une sucrerie importante.

Les courants polyphasés, comme vous le savez, messieurs, se sont répandus très rapidement pour la distribution de l'énergie dans de telles usines grâce à la simplicité des réceptrices qui ne nécessitent qu'un entretien presque nul; au contraire, pour les courants continus, le collecteur demande beaucoup d'entretien, une propreté plus grande et plus difficile à obtenir, spécialement dans le cas d'une usine comme la sucrerie dont je parle et dans laquelle on rencontre à chaque instant des liquides plus ou moins visqueux et des poussières qui se fixent près du collecteur.

Assez souvent, j'ai été amené à comparer ces deux systèmes dans

des projets et j'ai eu là l'occasion de voir leurs avantages et leurs inconvénients respectifs. M. Korda.

Les quelques points sur lesquels je me permets d'attirer votre attention sont les suivants.

Au point de vue de l'entretien, comme je viens de le dire, et pour le cas que j'ai cité, il n'y a pas à hésiter, tout l'avantage est pour le courant polyphasé.

Seulement, voici un inconvénient qui se présente. Dans une usine comme celle que j'ai prise pour exemple, il est impossible d'adopter des courants à haute tension, précisément à cause de ces liquides visqueux et de ces poussières dont j'ai parlé ; la propreté sur laquelle on peut compter est trés relative, et l'encrassement qui en résulte interdit l'emploi de ces courants à haute tension. Aussi la direction de l'usine limite l'ingénieur électricien à une tension qui ne dépasse guère 200 volts, parceque les tensions efficaces dépassant 200 volts pour un courant alternatif donnent comme valeur maxima des tensions qui commencent déjà à être considérées comme dangereuses. Or, dans cette usine, vous avez à actionner de nombreux moteurs, des centrifuges à sucre, par exemple de grandes dimensions, et ces centrifuges demandent du courant de grande intensité, surtout au démarrage.

Il faut donc canaliser des courants puissants. Or, le propriétaire de l'usine veut dépenser le moins possible pour la canalisation, et, à cause du prix, préfere les cables nus aux cables isolés. Comme on ne peut pas tordre ensemble les trois cables nus comme on aurait pu le faire avec les cables isolés afin d'éviter l'effet de la self induction, on est obligé de les placer aussi près que possible les uns des autres. Mais il y a forcément une limite à leur écartement à cause de la tension et de l'état de propreté peu sur. Voilà donc encore une nouvelle cause de courant dewatté pour l'ingénieur électricien chargé du projet d'installation, surtout si la station centrale d'énergie électrique se trouve un peu éloignée des ateliers dans lesquels la force motrice est employée. Si elle est, par exemple, à une distance de 200 ou de 250 mètres, la self-induction de la ligne va jouer déjà un grand rôle dans une usine d'une certaine importance.

A l'augmentation de l'intensité du courant provenant du décalage des moteurs vient donc s'ajouter la chûte de tension provenant de la self induction de la ligne.

En outre, dans bien des cas, l'on ne vous accorde pas une machine motrice spéciale pour l'excitatrice ; le propriétaire de l'usine se dit que, s'il employait du courant continu, la même machine lui donnerait l'excitation, et qu'il n'aurait pas besoin d'une machine spéciale. Se basant sur ces considérations, il vous demande donc d'établir un devis en prévoyant l'excitatrice sur la même machine que la génératrice. Il en résulte une troisième raison qui vous limite en ce qui concerne le voltage du réseau. En effet, au moment de la plus forte charge de l'alternateur, la machine à vapeur se ralentit ; l'excitatrice se ralentit aussi, et, quand l'on a le plus besoin de voltage, l'excitatrice, comme l'on dit vulgairement, nous laisse en plan. Cette diminution du voltage est, en effet, comme vous le voyez, en raison directe du carré de la diminution du nombre de tours de la machine.

M. Korda.

Voilà donc trois raisons qui font que, pour des applications du genre de celle dont j'ai parlé, on est forcé de choisir une machine d'une capacité plus grande que si l'on employait du courant continu.

Voici maintenant que le remède commence à se faire jour. Comme vous le savez, l'on a commencé, dans ces derniers temps,—et c'est l'Exposition Universelle de 1900 qui en a fait la première application pratique—à s'occuper du compoundage des alternateurs; je crois, en effet, que, dans des cas analogues, le compoundage est tout indiqué, et non seulement le compoundage mais l'hyper-compoundage, car, non seulement il faudrait pouvoir compounder les alternateurs, mais il faudrait aussi pouvoir arriver à l'hyper-compoundage en ce qui concerne la canalisation pour tenir tète à l'abaissement du voltage provenant de la self induction de la canalisation et des moteurs.

Je crois, par conséquent que, le jour où cette application dont nous avons vu la première apparition pratique à l'Exposition Universelle se généralisera, la situation du courant polyphasé, par rapport au courant continu s'améliorera encore.

Tout ce que je viens de dire n'a rien à voir avec une distribution d'énergie électrique dans une grande ville, parceque dans ce cas, l'on a une haute tension, et la chute du potentiel est proportionnellement très faible; les intensités étant très faibles, la valeur de la contre force électromotrice de self-induction correspondante est faible: aussi ces difficultés dont je parlais s'éliminent en quelque sorte d'elles mêmes. Mais lorsque l'on a une grande usine à desservir, et qu'il faut employer de grandes intensités de courant sous une basse tension les trois causes que j'ai citées se présentent, et l'on est obligé, naturellement, d'en tenir compte.

Professor Crocker.

Professor F. B. CROCKER: I think now that the discussion has been opened, and the subject generally covered, that the time has come when we may confine ourselves to a few special points. The subject of our discussion is with special regard to interference. I do not think that is the most important point, but as that is the subject we should apply our remarks largely to that. There are two interference effects that electric currents produce. I think they might be classified as the inductive and the leakage effects. Under the head of inductive I should include the magnetic effect, because the inductive effect is the magnetic effect, and *vice versâ*. Now, the inductive effect of the direct current is purely magnetic, it produces only magnetic effects in its vicinity. Therefore its disturbing effect is upon magnetic apparatus in magnetic observatories or upon magnetic apparatus generally. But there are not many magnetic observatories in the world, and, as Dr. Kennelly observed, they might be relegated to a point where they would not be interfered with. It does not seem to me that the progress of the electric art ought to be influenced greatly by the existence of a few magnetic observatories, and certainly it would not be so in many places. So I should be inclined to agree with my fellow-member and dismiss that point as not very serious, to say the least.

The alternating current also has an inductive effect, viz., the production of currents in its neighbourhood. It also produces a field, but that field being alternating produces no permanent effect upon magnetic

Professor Crocker.

apparatus. But the current inductive effect is produced solely by the alternating current, and that I should consider the more serious, because we have many more telephones or even telephone exchanges than we have magnetic observatories. As Sir William Preece has said, we can largely avoid that inductive effect by metallic circuits. But there are cases where we want wires overhead, and under those conditions we can hardly eliminate the inductive effect except by transposition of the wires, which is not a complete preventive. Furthermore, in certain cases and in smaller towns grounded circuits are used, and it seems to me that the inductive effect which produces a current in a neighbouring conductor is a more serious disturbance than that of the production of a magnetic field. I think that is so at the present time, and I think it will always be so. Therefore I should say that on that account the alternating current is more guilty than the direct; in other words its disturbing effect without leakage is greater than that of the direct current. Now, the leakage effect, unfortunately, is much more serious with the direct current. The leakage of direct current is that which produces the electrolytic effect, and is the most serious interference that electric currents produce on other apparatus or other interests. But that leakage is something we can control to a great extent. The production of a magnetic field and the inductive effects are much more elusive than mere leakage. In high-tension conductors, overhead or underground, the leakage quantity is exceedingly small. It must be so. If considerable leakage occurred in an underground conductor at several thousand volts it would produce a short circuit or a ground. But there is a leakage occurring in low-tension conductors. I think that is because we have allowed it to exist. If we insulate high-pressure conductors as well as we do, we can insulate low-pressure conductors equally well or better. I had occasion to test the underground network of New York City, many miles in extent, and the system was split up in sections to enable this to be carried out. We found that the leakage was not excessive; it is a very small percentage of the current—considerably less than 1 per cent., as the test showed at the time. I am referring to electric lighting conductors which are not grounded. A similar result is found, I believe, by a comparison of the total output with the output that is useful. That shows that the leakage is a small quantity. In the gas industry that is not the case. A very large percentage of gas—10 or 20 per cent. in the case of New York—is lost by leakage. But that is not true in electric distribution. So I should say that the fact that we have now in electric conductors, overhead or underground, a considerable leakage, is a temporary condition which can be overcome. I am sure electric conductors, except those purposely grounded, can be so laid that the leakage is a negligible quantity, even for long-continued electrolytic effects. Now, with the grounded trolley system, the single-wire trolley, the current must go into the earth. But there again by the use of improved methods, return feeders, and more perfect bonding, we have reduced that promiscuous flow of current through the earth, until now it is very much less than it was before, and I think it can be brought down to a quantity which is also insignificant. If it can be reduced to the figure which Professor Ayrton

Professor Crocker.

mentioned—one-fifth of a volt—if that were the difference of potential, it would be far below any dangerous electrolytic limit. So, apparently, the interference is not so very different in the two cases—that is to say, the alternating has a greater inductive effect without actual transfer of current, and the direct current has much more serious electrolytic effects. But those can be and have been largely overcome by more perfect construction.

I should like to say just a word on the motor question. Sir William Preece cited a certain instance where direct current machines had been replaced by alternating. I know of several other instances where alternating have been replaced by direct, so that evidence is not at all conclusive. That point alone could well occupy us for much more than the time we have at our disposal. I will simply say now that so far as efficiency is concerned the two kinds of motors are almost identical. I have in my possession efficiency curves of the latest induction motors from the Westinghouse and General Electric Companies, and I compared them with the efficiency curves of direct current machines of the same size and the agreement was almost perfect; the two curves coincided almost exactly at full load and at all loads above one-third of full load. Below that the agreement was not so close.

A Member.

A MEMBER: What do you call the same size?

Professor Crocker.

Professor CROCKER: I mean in rated capacity, also in actual capacity. The agreement of the two sets of curves was remarkable and complete, except at very small fractions of full power the direct-current motor has a better efficiency, but at one-half to full load the agreement was almost perfect.

Sir W. Preece

Sir WILLIAM PREECE: What was the efficiency in per cent.?

Professor Crocker.

Professor CROCKER: It depends on the size. The efficiency depends on the capacity of the machines. For example, a small machine, a one kilowatt alternating-current induction motor, would have the same efficiency as a one kilowatt direct-current machine between half and full power, and the curves representing that efficiency would agree exactly.

Sir W. Preece

Sir WILLIAM PREECE: What percentage of 100?

Prof Crocker

Professor CROCKER: That depends on the size of the machine.

Sir W. Preece

Sir WILLIAM PREECE: Take one kilowatt?

Prof Crocker

Professor CROCKER: I do not recollect that figure.

Sir W. Preece

Sir WILLIAM PREECE: Was it over 90 per cent?

Prof Crocker

Professor CROCKER: No, it was not; but we compare the two systems, and I say there is no choice in that respect, except that the direct-current motor was higher efficiency at light load; at other loads the two are equal.

Now as to regulation for constant speed, the two machines are equivalent. A percentage of reduction of speed occurs when the machine is loaded from zero to full load. First-class direct and alternating current machines are equally good in that respect for constant speed; but when you regulate for variable speed the direct-current motor has a great advantage over the alternating-current motor. It is equal in efficiency, it is equal in regulation for constant

speed, but the direct-current machine is superior for variable speed. That applies not only to stationary motors, with which I am most familiar, but it applies also to electric railway machines, and I think is equally important for stationary and for traction purposes. It is in that respect that the direct current has its advantage for power purposes over the alternating. I do not think it would be fair to the direct current, or proper to this occasion to allow that point to pass unquestioned. Professor Crocker.

Mr. W. M. MORDEY: With several of our American visitors I have discussed during our meetings the question of earth drop on the return circuits of tramways, and I have found a general disposition to suppose the Board of Trade regulations restricting the drop within 7 volts was not adhered to, and could not be adhered to. I have just carried out a very complete series of tests on many miles of tramways in England; and one of the things I had to investigate was that question of earth drop. I found in that system, running under the fullest load conditions, that the drop of potential never exceeded 5 volts. You will notice in tramway stations that the recording instruments which we always use, but which I think are not used in America, may momentarily indicate more than 7 volts; those instruments indicate higher momentary effects than the real value. For instance, if you suddenly switch one of those instruments on to a steady pressure of 6 volts, it will usually swing to about 10 volts. One of the differences between English and American practice is, I think, apart from the question of scale, that great attention has been given to this question of earth drop, and to the continuous recording of what is happening. The Board of Trade regulations are strictly enforced. I am sure the result has been good. I hope in this discussion we shall obtain from our American visitors some actual quantitative results arising from electrolysis. The real point which I think was intended to be brought out was whether or not electrolysis, quite apart from other questions, would not be a determining factor in the development of systems of supply, at least where earthed conductors were used. Mr. Mordey

I will ask you to bear in mind the one and only absolute cure for all troubles of this sort, whether direct or alternating currents are used—the insulation of both conductors. I expect to find it applied in the future in all railway cases and in all conduit cases, whether for direct or for alternating current. Quite apart from the avoidance of electrolytic effects it has many advantages. To comply with Board of Trade regulations we have to use boosters and great quantities of copper to assist the return circuit. There would be no objection to 25 or 50 volts—or even more, instead of 7—if we had not to consider electrolysis. We could, if we wished—and if it were economical to do so—have as big a drop on our return as on our trolley line if we used an insulated return; and we should get rid of bonding and of sparking at dirty rails, and of electrolysis. Information as to the results of the working of the double trolley system at Cincinnati, where it is or has been employed on a large scale, would be of great assistance to us. We should like to know if, in America, in your conduit or railway work, you are making any efforts to avoid the objectionable earth return.

Whether in the future there will be any preponderating system

Mr. Mordey. still seems quite uncertain. It may be the system is going to be alternating for transmission and direct for distribution; but I cannot help thinking that ultimate simplicity will lead to the use of alternating currents for almost everything, at least where we have long-distance transmission or large areas. In railway work where we begin with alternating currents, the simplicity of transformation will probably ultimately lead to the use of alternating throughout. There is, however, much to be said for Mr. Lennard's system, with his rotary convertor on the car, if direct currents have any part. My own feeling, in spite of present fashions in England, is that sooner or later we shall have in all large systems the alternating current right through. I believe the rotary transformer is a make-shift, to be cleared away sooner or later for railway work; it is quite unnecessary for lighting and only indispensable for electrolytic work.

Some of you may go on to Switzerland from here, and may see the examples of alternating work there. You will see the Burgdorf-Thun Railway and the Engelberg and Jungfrau Mountain Railways, where many questions are disposed of. If you can start a train on a mountain rack railway you can start one anywhere.

We have, during the last few days, seen the Central London Railway, and highly appreciate the facilities afforded us by the Company during our visit. But all of us who have had to do with the estimating of engineering work will have felt that if all the cost of those sub-stations—their static and rotary transformers and so on, their first cost, their maintenance, their working cost in power and labour—could be realised and put into conductors, we should have, for that case at least, a simple system which would be safer and probably more economical in first cost, certainly in working cost afterwards.

The question of capacity has been referred to. It is more serious in alternating underground work than is generally realised. I recently had to investigate some difficulties due to capacity on a system of two hundred and fifty miles of underground cables in St. Petersburg. There is really much less difficulty than is generally supposed in overcoming most of the effects of capacity of such mains. I wish I had time to say more on the subject, but must leave it to an opportunity which I hope may be granted later.

I should like to refer to one "existing interest." I mean the interest of the public and of the scientific laboratories and observatories. There can be no question that ultimately these institutions will have to be removed from the centres of large populations where there are great applications of electricity, unless the methods adopted in those institutions can be so ordered as not to be interfered with by such applications. Fortunately we have at the Board of Trade a striking object-lesson. As far as I know, the Board of Trade electrical standards laboratory is the only electrical institution in England which is legally obliged to be accurate. It is laid out in such a way, the responsible officials say, that although they are in the heart of London they do not mind what electrical applications are made in London; their arrangements are such that they can carry on their work with the accuracy demanded by law without any reference to what is going on

outside. That does not touch the question of measuring the magnetism of the earth. But surely that should be measured where it is the magnetism of the earth and not that due to the application of electricity to the use and service of man. There was a case in London of an institution, whose work I would not for a moment depreciate, where the influence of that institution was exerted successfully to prevent what would have been a very great convenience to the population of London, the running of an underground electric railway. It is difficult to speak calmly of such an action. There was no sort of proportion between the two interests; yet, though the object of the scheme was so excellent, the smaller interests were allowed to stand in the way of the benefit and the convenience of the population of London. Mr. Mordey.

Mr. C. O. MAILLOUX: The subject has been so well discussed—it has been nearly exhausted already—that there is very little to be added. There is one point only which I think has not yet been fully discussed. In our country we would take a broader interpretation of the topic of discussion than is being taken here. The effects produced upon certain industries oftentimes effect the feasibility of the industry, and in this connection I have been able to note the practical difference between the two systems, and the one which in fact determines the feasibility of either one, or its want of adaptability, according to the case. One of the important points, which it seems to me has been neglected, is the influence of the power factor in the case of the alternating current. My colleague, Professor Crocker, has pointed out quite clearly the similarity in results obtainable between the alternating and the direct-current motors. He has also pointed out that at constant speed they work quite alike. But he has neglected to note that the influence of the power factor on alternating currents is a matter of importance. As we know, when the electromotive force of the source of supply of a direct-current shunt-wound motor varies, the magnetic field of the motor varies, but that has the effect of merely changing the armature current to an extent necessary to maintain the speed; so that although there is speed fluctuation, it is not so great as when the electromotive force varies in the case of the alternating-current motor, because the speed is in this case a higher function of the electromotive force. In our country we have several isolated plants which assume the dignity and importance of central stations. It is not uncommon for us to have isolated plants of one thousand to three thousand horse power, which distribute energy over a zone of about half a mile radius. It is under such conditions that these difficulties are to be noticed. I remember an instance where a certain process for manufacturing coffee was employed, the electric current for which was furnished from a power station which also supplied lights to the district. It was found that owing to the enormous wattless current produced at the starting of the motors, on many occasions the line and even the generators would be overloaded, the result being that the current supply was cut off by the fuses blowing off, and that the machinery which was used in that coffee mill was put out of action, oftentimes at critical moments, when the stoppage meant great loss. The alternating-current motor system became absolutely inadmissible in this case from that circumstance, and Mr. Mailloux.

Mr. Mailloux. had to be abandoned. One of the great objections, as you know, to the alternating-current motor of to-day is the fact that it takes such a large current at the time of starting. Its large wattless component is a serious matter, affecting as it does the working capacity of a line where the motors are constantly stopping and starting. Where all the motors are running together at an approximately constant load and at constant speed, the problem is simple, and there are no industrial reasons why the alternating current should not be placed upon an equal footing with the other. But where the motors are constantly stopping and starting, and especially where the distribution of power is constantly changing, and also where you load certain feeders more than others, the disturbance becomes very important. It has to be seriously taken into consideration by the designing engineer in laying out the plant. I have had occasion to instal a plant in a sugar refinery which required 2,000 H.P., and it was decided to adhere to continuous-current motors partly for these reasons, and also for the reason that in cases where variable speeds are required, and where the machinery is required to run at intermediate speeds, there can be no question that the direct-current system is at the present time the most suitable, if not indeed the only feasible one. I wish in this connection to speak of the pertinent remarks made by our French colleague in reference to one of the features, one of the industrial conditions, which oftentimes influences the selection of systems. I refer to the cost of the wiring. It is true that to-day, at least for the larger distributing conductors in buildings, and within a short radius, as well as for underground purposes (where we are obliged to use concentric or twisted conductors), the cost of the wiring is necessarily much greater than in the smaller branches and net works, such as the local lines or mains which run to individual motors. In our country the problem is, to some extent, solved, since we use iron conduits any way for these lines. Our insurance regulations prescribe, indeed practically compel, the use of iron conduits for the smaller lines, and, usually, we have two conductors, twisted or concentric, as the case may be, laid in iron conduit, whether the circuit work be used for direct or for alternating currents; but in the case of the larger conductors the arrangement need not necessarily be the same in both cases. With alternating current we must still use a twin or duplex conductor laid in iron conduit, to keep down the reactance drop. With direct current there is no reactance, and we are not compelled to use twin conductors. It is often found to be very much cheaper to use two separate conduits, and two ready-made single conductors (especially in the case of the larger feeders or mains), than to use one single conduit very much larger in size and a cable specially made at relatively great expense. The mechanical difficulties in laying the larger conduits, their greater obtrusiveness and the greater space occupied by them, especially at bends, turns, offsets, &c., would be sufficiently objectionable even if they did not, as they do, in most cases, make the cost relatively greater.

Professor Thompson. Professor SILVANUS THOMPSON: We have had no observations whatever upon the relative interference of alternating and continuous currents on board ship. It is of absolutely vital importance that there

Professor Thompson

shall be no interference with the magnetism of the compass, and yet, extraordinary as it may seem, almost all ships that are equipped with the electric light are equipped with continuous current apparatus. I never could understand why that was. Some of the earliest vessels had alternating currents on a three-wire system, with the skin of the ship serving as a middle wire, but this system was succeeded by one with the very worst kind of continuous-current generator which could be put on board, viz., the bi-polar. I hope to see a complete revulsion in ship-fitting from this plan.

No reference has been made to the somewhat greater danger of fire that exists where conductors are carried through damp places if those conductors are served with continuous current. Electrolysis beginning at some leak will develop a current which eventually heats and destroys the insulation at that point, and thus originates a fire. With an alternating current you are less likely to have that occurrence. On the other hand, I suppose switch-makers will tell us that alternating switches are more expensive than continuous. No one has mentioned that while for arc-lighting admittedly there is some advantage in using continuous currents, for glow-lamps there is an advantage in using the alternating current. Not that there is any higher efficiency: that fallacy has long been disposed of; but if you use a continuous current for glow-lamp purposes, and the distribution is to take place over any large area, it becomes absolutely necessary to go to the high-voltage lamps working 200 to 250 volts. Now any one who has taken the trouble to measure the reputed efficiency of high-voltage glow-lamps will know how inferior they are to the 100-volt glow-lamps; things which are supposed to be taking 3½ watts per candle being found actually to take 6, 7, and 8 watts per candle. I think there will be a great revulsion when the facts are known about the inefficiency of high-voltage glow-lamps. I prefer to have 50-volt glow-lamps; they are better in every way, and last longer. This is impracticable with a continuous current, but with the alternating current it can be done where there are house-to-house transformers; and so, using low voltage lamps, you can work to a much greater distance with alternating than with a continuous current.

I was sorry to hear Dr. Kennelly rake up the fallacy of there being a greater danger to persons from the alternating than from the continuous current. But that is a revival of a bit of the old electro-politics. When people wanted to damn the prospects of alternating currents and show how much better they were for electrocution, this was the line they took. I hope those arguments have disappeared. I think there is some evidence that the alternating current is not so dangerous as the continuous current; that the shock which is given by the alternating currents throws backwards the unfortunate person who receives it, and does not contract his muscles upon the conductor in the way that a continuous current does. The researches of Prof. H. F. Weber must not be overlooked. I prefer to leave that question to M. d'Arsonval, who understands these electro-physiological effects better than we electrical engineers.

Professor Ayrton raised the question of the electrolysis produced

Professor Thompson.

by the alternating currents. Might I point out that the question whether alternating current will, in any given circumstances, produce continuous electrolysis depends very largely upon the question of the relative area of the electrodes employed and the density of the current. Because whether gas is disengaged at that area or not during the period depends on the density to which that gas accumulates, and whether it is given off. In fact the question whether the polarisation becomes irreversible or not is very largely a question of scale.

Lastly, I will draw attention to certain points connected with electric traction on a large scale. I re-echo the suggestion of Mr. Mordey, that it is well worth while for one who has not seen those electric railways in Switzerland to visit them, and to see how admirably the three-phase current is adapted for starting trains under the most severe circumstances possible. It is known from the experiments of Professor Carus-Wilson that the difficulty of the acceleration of the motor at starting is after all imaginary; and that it requires an extra percentage of current is also a fallacy. Every motor started upon a load takes more current than when running on that load; and this is true also of the tri-phase motor. The current required to produce rapid acceleration is even more important than the starting-torque; and the three-phase system, instead of being worse, is distinctly better.

We have had in London several recent object-lessons on electric traction. One of them has been, from one point of view, a gigantic success, but also a total failure. Little more than a year ago we were told that one of our millionaire railway companies had put down a sum of, I think, £30,000, to have experiments tried upon the Underground Railway. I referred nearly a year ago to this supposed experiment, and pointed out that the one experiment which was wanted for electric traction was to ascertain whether a three-phase motor arrangement would be better than a continuous one. We knew pretty well, but we wanted it tested, we wanted a verification. That experiment has not yet been tried. There were called in several engineers of the highest distinction, and they were aided by the constructional ability of Messrs. Siemens Brothers. But the only thing which has been tried, notwithstanding that all the resources of a great railway company stood behind the experimentation—I say it before Sir William Preece's face—all that they have succeeded in doing is merely carrying out on a large scale what was done at Gross Lichterfelde, by Siemens and Halske, fifteen years ago, viz., establish the fact that you can drive by the continuous current, using conducting rails put beside the ordinary rails. The London press has pronounced this experiment to be a perfect success. I regard it, on the contrary, as an abject failure, inasmuch as it gave us no further information.

Lastly, if you are going to have, as I think we shall have, trains running at 100 or even 150 miles an hour, driven electrically, there will be no chance of success if we have to depend upon a motor which has got a commutator upon it. I speak of a new growing interest, viz., exceedingly rapid transit, and I venture to say that for exceedingly rapid transit the only chance of possible success is

to take advantage of that which is the finest thing of all in electrical engineering, the perfect flexibility and adaptability to requirements afforded by the current when that current is an alternating one. Professor Thompson.

Mr. H. WARD LEONARD: I have a fair acquaintance with what can be accomplished with the continuous current as regards large starting-torque with a small amount of energy, and have given considerable attention to the operation of large motors which have to be started under very heavy loads, and operated at different speeds and reversed. Mr. Ward Leonard.

I have lately seen one of the recent installations employing three-phase motors upon railway work in Switzerland, and I must say that when the car was started it seemed to me as though there were about one donkey-power doing the accelerating. It did not convey the impression to my mind of being able, with moderate power, to produce the heavy starting-torque required for the rapid acceleration which is such an important factor in electric railway work and many other important applications of electric motors.

Perhaps my views on this point are a little biassed, but it seems to me that when we consider large railway motors the most important points are: rapid acceleration, small starting energy, perfect and simple control and ease of reversing, and the restoration into the circuit of the energy at present wasted upon the brakes.

We find the possibility of obtaining all of these points in the continuous current to a degree to which there is no promise as yet in the alternating current.

When we consider the question of electrolysis, we are met with difficulties in attempting to use a continuous current in the ground return circuit, which seem insuperable except by capital expenditures which are entirely uncommercial.

When we wish to transmit very large amounts of energy over the long distances which are desirable, we all agree that the alternating current is the only suitable one for the purpose.

These considerations have, for many years past, made me believe that we ought to use the alternating current for the generation and transmission of our energy, and that we should have upon the moving vehicle some means of transforming the alternating current into a continuous current of controllable E.M.F., and that we should use this continuous current of variable E.M.F. for operating the propelling motors at the variable speeds required in practice.

These arrangements would give us large starting-torque with a small consumption of energy, and even in the case of the largest motors will give perfect control at any desired speed and simplicity in reversing. It eliminates all difficulties due to the electrolytic action of the continuous current in the ground circuit. It gives us the power to employ motors of practically unlimited power at practically unlimited distances for railway and other variable speed uses, and entirely eliminates the expensive and inefficient sub-stations of to-day.

It seems to me that the electric railway is the application of electric power which is going to exert the determining influence upon the methods of using electric energy in the future, especially the railway motors of very large size; and it seems to me a significant fact that,

Mr. Ward Leonard. after twelve years of development by the leading engineers of all countries, there are no alternating current motors exhibited at this exposition for railway service or any other duty having similar requirements.

Professor Perry. Professor PERRY: Mr. Carl Hering, M. Mascart and I waive our right to say anything on this question, although we could, of course, join heartily on one or other side. I beg to say that we think it better to have no vote upon this discussion as it is an incomplete discussion—one which is adjourned. The specimen sent by the Board of Trade will be on view in our room in the British Pavilion.

At the conclusion of the discussion, brief references to certain objects possessing special or novel interest in the electrical sections of the International Exhibition were made successively by M. Hospitalier, Major-General Webber, Mr. Gavey, and Mr. Hering. Summaries of their remarks are appended, with the exception of those of Mr. Gavey, who has expanded his account of Class 26 into a paper to be read before the Institution in November (see page 73).

NOTICE OF EXHIBITS IN CLASS 23 IN THE PARIS EXHIBITION.

PRODUCTION ET UTILISATION MÉCANIQUES DE L'ÉLECTRICITÉ.

By E. HOSPITALIER.

In the Universal and International Exhibition of 1900, a whole group (Group V.) is devoted to the subject of Electricity; and this group is divided into five classes, numbered 23 to 27, of which the first-named (Class 23) is entitled, *Production et Utilisation Mécaniques de l'Électricité*. In the short space of time at my disposal I can only refer to the machines and apparatus possessing the most novel interest in this class, and I ask your indulgence if my enumeration of these is somewhat suggestive of a catalogue.

Continuous Current Dynamos.—Progress since 1889 in this class of machine is evidenced mainly in the constantly increasing power of the machines. The dynamos exhibited by the firm of Siemens Bros. and Co., of London, and M. Thury's constant-current dynamo shown by the Compagnie de l'Industrie Électrique, of Geneva, merit special examination.

Alternators.—The most powerful alternator shown is that of the Allgemeine Elektricitäts Gesellschaft (3,000 KW.). We should regard as evidence of progress made since 1889 the *amortisseur* of M. Maurice Leblanc (Joseph Farcot) which facilitates the coupling of alternators and their maintenance in synchronism, and the compounding exciters of M. Boucherot (Maison Bréguet) on the one hand, and of M. Maurice Leblanc (Maison Grammont) on the other hand, which permit the maintenance of constant potential, irrespective of variations of the load and of the shifting of phase. The powerful asynchronous three-phase motors of the Westinghouse Electric Co., which operate the moving platform and the electric railway within the Exhibition, are of very great interest and deserve a special visit. In 1889 simple alternating currents, now known as monophase, were alone in evidence, but to-day the greater number of the generating groups and of the machines exhibited are run by polyphase alternating current dynamos. All these generating groups are worth a visit, and to avoid invidious distinctions I prefer not to mention any one of them in particular.

As a step towards determining the limit of pressure that may be obtained direct from alternate-current generators, without using transformers, the Société l'Éclairage Électrique has constructed an alternator generating at 30,000 volts, which is worthy of special attention.

Transformers and Converters.—Transformers for converting alternating into alternating current call for no special remark; but the Société Alsacienne de Constructions Mécaniques show a very interesting booster for three-phase currents.

Motor-generators and Rotatory Converters, which were not in evidence at all in 1889, play a very important part in 1900, and I would call attention specially to the six-phase converter of the Société Alsacienne de Constructions Mécaniques, to the converter shown by the Société d'Électricité Alioth, and to M. Maurice Leblanc's converter with fixed magnetic and electric circuits.

Cables.—Great progress has been made since 1889 in the manufacture of cables, and very remarkable experiments are daily made by the Allgemeine Elektricitäts Gesellschaft, the firm of Pirelli (of Milan), and the Société des Câbles Berthond Borel et Cie., to illustrate the resistance of cables

at high pressure to disruptive discharges, and to demonstrate their electrostatic rigidity.

Accessories.—The handling of currents of great intensity or of high pressure has compelled constructors to study a special apparatus which had no existence in 1889, and of which some idea may be gained by a visit to the two switch-boards of the Exhibition for conveying the current from the groups of generators to the mains, the one for continuous, the other for alternating—single-, two-, or three-phase—currents. In the section of foreign generators Messrs. Siemens and Halske exhibit some extremely interesting experiments (in order to demonstrate the efficacy of their horned lightning arresters) in the production of electric flames, nearly two meters in length at the moment of extinction, in which from 300 to 400 KW. of energy are utilised, and producing a temperature sufficient to cause the direct combination of atmospheric oxygen and nitrogen.

Motors.—Tramway and automobile motors show many novelties in comparison with the corresponding class of exhibits in 1889, when the earliest industrial tramway motors timidly made their first appearance. Alternate-current motors, whether simple or polyphase, were then unknown, as well as special devices for starting, of which the Exhibition contains a certain number of interesting examples, among them being those of M. Boucherot, M. Max Déri, and M. Fischer-Hinnen.

Applications.—The mechanical applications of electricity in the Exhibition are innumerable, the machine-tools actuated by electric motors varying infinitely and defying enumeration.

I will now give place to Major-General Webber, who will refer to the exhibits in Class 27, as I have endeavoured to do to those in Class 23.

NOTICE OF EXHIBITS IN CLASS 27 IN THE PARIS EXHIBITION.

APPLICATIONS DIVERSES D'ÉLECTRICITÉ.

By MAJOR-GENERAL C. E. WEBBER, C.B., Past-President, Institution of Electrical Engineers.

This class includes scientific apparatus used in Electrical Laboratory Work; Electrical Measuring Instruments; Instruments and Apparatus used in Electrotherapeutics; the Electric Measuring of Time; Electrical Instruments and Apparatus used in Railways and on Public Works, and various other special applications.

In Class 27 the history of the development of instruments of precision and of measurement is illustrated in the hall of the Musée Centennal d'Électricité, which contains 249 exhibits and 210 books and manuscripts. The earliest of the former is a Coulomb balance, dated 1785, and of the latter a volume on the nature of magnetism, by J. T. Hannonio, dated 1562.

In the memoir on the subject of instruments of precision drawn up by the Commission and published in the French catalogue, we find the following :—

"Les circonstances, en réservant à l'Angleterre les premières opérations de cette délicate initiative, lui auront valu l'honneur d'avoir jeté les bases solides sur lesquelles a été érigé depuis, l'edifice actuel de la science electrique."

The design of those who are responsible for this part of the classification of objects exhibited in Class 27, namely instruments of precision, appears to be one that should be applauded by both engineers and physicists, because it is intended to emphasise the practical spirit of the scientist and the scientific attainments of the engineer, by showing that those instruments which in the hands of the *savant* are used for theoretical discovery, also assist the electrical engineer in his workshop, and in his practical application of the use of electrical energy to the daily use of mankind.

At the head of the list of exhibitors in Class 27, of what may be called instruments of precision, stand Mons. Jules Carpentier, of Paris, and Messrs. Siemens and Halske, of Berlin. These are followed in merit by Ducretet, Gramme, Abdank, and Gaiffe, of Paris; Professor Edelmann, of

Munich; James White, of Glasgow; also Professor R. Arno, of Italy, Hartmann and Braun, of Frankfort-on-Main, and Ganz, of Buda Pest.

It was unfortunate that the merits of the Weston Electrical Instrument Company of New Jersey were not sufficiently displayed by the variety of the objects they exhibited.

The Scientific Instrument Company of Cambridge, of which Professor Darwin is the directing genius, have placed their Callender's Patent Electric Recorder, and their Duddell's oscillograph in Class 15, where their great merits might have escaped attention but for my successful efforts to have them examined by the jury of Class 27.

Although the apparent intention of the French classification was to keep all electrical measuring instruments for scientific purposes in Group V., a large number of the best have been exhibited by foreign countries—especially by Germany—amongst the philosophical instruments in Class 15, Group III. Amongst these is the Reichsanstalt standard dynamometer.

The instruments manufactured and exhibited by Siemens and Halske, by Jules Carpentier, and for Lord Kelvin by James White, are too well known for their accuracy and perfection of workmanship to require any description on my part. A careful inspection of these exhibits would alone occupy many hours.

After those exhibits to which I have referred as meriting the highest awards, our members cannot do better than make a careful inspection of the exhibits of measuring instruments by Ducretet and by Gaiffe.

The comparison in each branch of this manufacture, which impressed itself on me between 1878, when I was British juror dealing with similar objects and when these manufacturers were in the infant stage of their work, and in 1900, is a startling revelation of the development which one generation has made in these appliances which are now indispensable.

From the point of view of the needs of the electrical engineer, the potentiometers exhibited by Messrs. Crompton, by Messrs. Braun and Hartmann, by J. Carpentier and by Arnoux, represent distinct types of form for instruments all having similar uses. Messrs. Braun and Hartmann's work

is especially noteworthy for its excellence of design and small cost.

But it is in the application of electricity to therapeutics, that this exhibition presents appliances of perhaps greatest ingenuity. Although in the United States invention has perhaps made in the past some original advances in this direction, there is nothing worth mentioning shown at Paris by that country, except, perhaps, an electro-magnet for extracting metallic substances from the human eye, exhibited by E. B. Meyrowitz, of New York.

In the French section of this speciality, however, we find everywhere the triumphant results of the scientific life-work of Dr. d'Arsonval, Director-General in the *Collège de France*, of the senior school and laboratory which teaches biological physics, a school which has been entirely created by that celebrated scientist. The instruments, the origin and design of many of which are due to his researches, are made and exhibited by Louis Bonetti, Bréguet, C. Chardin, Gaiffe, J. Guénet, Radiguet and Massiot, and notably by C. Verdin—all of Paris. Messes. Gaiffe's cage for subjecting the human body to high-frequency radiation, and his self-registering milliampere meter, are worthy of note by the visitor. To these in the same line may be added Hirschmann, of Berlin.

From Germany, in Classes 15, 27, and 30, there are five exhibitors of electro-medical, physiological and biological instruments. Amongst these is the Allgemeine Elektrizitäts-Gesellschaft.

The apparatus for applying currents of high frequency in physiological research, and for radiography, which are exhibited by the firms mentioned above, are the most striking example of the interest taken in the application of electricity to the uses of medical science, as to which there is still so much left to the physiologist to discover.

The absence of Great Britain in this field is so conspicuous, that one wonders if our want of practical enterprise in this direction is due to conditions of humidity of climate, which opposes itself to success without the use of special and expensive precautions.

In Class 27 are included some other applications of electricity to industrial works.

There are exhibits, not however of great note, in con-

nection with time-keeping. 1. Of electric clocks, in which electricity is the actuator of motion in each; 2. The hourly or daily regulation of any number of clocks connected with a regulating timepiece; 3. The working of time-keepers or electro-magnetic indicators worked by means of a distributing timepiece. All these are included in the French expression "*l'horlogerie electrique.*" A small exhibit of J. J. Stockall & Sons, of Clerkenwell Road, London, which is in Class 96, in the *Esplanade des Invalides*, presents some novel features. Except with what is shown by the Herzog Telesceme Company of New York, the United States, in the forefront of invention, sends nothing. The house of Henry Lepante, 11, Rue Desnouettes, Paris, and the Société Industrielle des Telephones, and d'Arlincourt, show high-class work in these respects. But in front of all, as might be expected, the name of Peyer, Favarger & Co., of Neuchâtel, stands pre-eminent.

The use of electrical appliances in connection with the working of railways and other public works has received great development on the Continent since 1878. Neither Great Britain, or her Colonies, which at that period (when Mr. Spagnoletti was my co-juror) was well in advance in the invention and use of apparatus for railway working, has sent one object in this connection to this (truly) Great International Exhibition at Paris of 1900. The use of solenoids and small motors for working heavy signals and controlling gates at a distance, by energy stored and delivered from accumulators, is illustrated by Jules Guénet and by Postel-Vinay, both of Paris. The latter exhibits in Railways. An examination of what is exhibited by the great French railway companies in this connection causes regret, even for instructional reasons, that England and the United States have abstained.

It is impossible, within the limits of time allowed me, to do more than bring a few of the special applications of the use of electrical energy to notice, and of these there are too few, especially of exhibits of materials used in the electrical industries. Only mica and micanite, one in the French, one in the United States sections, are worth a visit.

Of the materials for primary batteries there is not one important show.

There, is, however, one interesting departure in electrical

heating and cooking, by Parvillée Bros., of 29, Rue Gauthey, Paris. Where the heat is required, either for warming air in circulation, or in close proximity to the object to be cooked, whether to be roasted, boiled, or braised, resistances made of "metallo-ceramique Parvillée" are fixed, which, by the passage of a current of 30 to 35 volts, are raised at the middle (but not at the ends, where they are held like a safety-fuse) to a condition of dull incandescence. The only description of these that I have seen will be found at page 385 of *L'Électricien* of June 23, 1900. The Jury of Class 27 inspected the use of these at the kitchen of one of the largest restaurants on the Quay d'Orsay, where all the processes of cooking for the *dejeûner* of a large *clientèle* was in progress.

There are several fair examples of lightning-conductor work, and in Class 15 Messrs. Hartmann and Braun, of Frankfort, exhibit apparatus for measuring terrestrial magnetism and its variations, together with a means of testing samples of iron.

There are several ingenious fire and water level indicators; and B. Ougrimoff, of St. Petersburg, exhibits an electric boiler for heating steam to a pressure for house distribution, which might be practical, though costly.

For purposes of Naval equipment Messrs. Siemens and Halske make a very complete show, combining means of controlling artillery and torpedo projectiles, the steaming and the steering from one or several points in a warship, with the use of the pressure (110° volts) employed for lighting the ship as well as by special moisture-proof telephones. Their special arrangements for pneumatically counter-poising heavy lever handles, for acknowledging back all signals and calls, for synchronising and for lighting each handle, dial, and indicator, are well worthy of attention.

NOTICE OF EXHIBITS IN CLASSES 24 AND 25 IN THE PARIS EXHIBITION.

ÉLECTRO-CHEMIE AND ÉCLAIRAGE ÉLECTRIQUE.

By CARL HERING, President of American Institute of Electrical Engineers.

One of the most interesting exhibits is that of the Nernst lamp, which is shown in operation in quite large numbers in the pavilion of the Allgemeine Electricitäts Gesellschaft of Berlin. The filament is made chiefly of magnesia, together with some of the rare earths, like thoria; it is shorter and thicker than in the carbon incandescent lamp. The lamps are now made for 220 volts, continuous or alternating, and for 25 and 50 c.p. and over; they therefore do not compete directly with the low-candle-power, low-voltage, carbon-filament lamp. The efficiency is 1·5 watts per Hefner candle, which is about twice as good as that of the present carbon lamps; besides this high efficiency, it has the advantage of the high voltage. It is made in two forms, in one of which the filament is preheated with a match or alcohol torch, the bulb being open; and in the other it is heated with a neighbouring fine platinum wire, which is automatically cut out of circuit when the filament conducts. The filament has a rapidly falling temperature coefficient, which is a great disadvantage, as it would make the lamp very sensitive to changes in voltage; to overcome this a very fine iron wire is always in series with the filament, and is so proportioned that for the normal current it is heated to a temperature at which it has a very rapidly rising characteristic, so that the lamp as a whole is not very sensitive to changes in voltage; this iron wire absorbs about 10 per cent. of the voltage. The perishable parts are so arranged that they are easily replaceable at a cost of only about 25 per cent. of that of the original lamp.

The Bremer arc lamp is a novel departure of some interest. The carbons contain certain metallic salts like borax, or those of magnesium or calcium, especially calcium fluoride, which, at the temperature of the arc, emit white oxides, that deposit on receptacles near the arc and act partly as a white reflector and partly as a Nernst conductor,

forming a broad illuminated surface, the arc being 4 to 5 c.m. in length. Wedding, who is an authority, found the efficiency to be 0·13 watts per mean hemispherical candle The carbon consumption is about double that of the ordinary lamp.

The Pulsford method of making a vacuum in lamps by means of a chemical which absorbs the residual air, is shown in operation; it is not new. Weismann shows a system of using very low voltage lamps with a small transformer for each group, claiming thereby to increase the light efficiency by about 50 per cent.; it seems very doubtful whether the attending disadvantages are not greater than the alleged advantages. The enclosed arc lamps which are exhibited, are all American or of American origin ; four types are exhibited, in one of which a life of 300 hours is claimed: the French claim that the light is too blue and unsteady. A number of arc lamps of interest are exhibited in the French section, and they all seem to burn very steadily. The general type of mechanism is that of the brake escapement, which feeds very gradually; all the lamps are intended to be run on constant potential circuits, generally two in series, but in some cases as many as three, and the lamps are then generally differential, having both a series and a shunt coil; some of them are for so small a current as two or three amperes, and burn very well.

Those interested in search-lights will find some very fine exhibits, chiefly in the French section ; also a few in the German department.

The exhibit of chandeliers is almost entirely French, and they are, as a rule, very artistic. They are found chiefly in the Gallery and in the Invalides.

Three underground cable exhibits are shown in operation, subjected to from 25,000 to 30,000 volts, one in the German section, another in the Italian, and a third in the French. In the two former rubber is used, while in the latter the insulation is impregnated paper without any rubber, which adds to the interest of the exhibit.

There are a great many exhibits of meters, but it seems that the well-known Thomson meter is the one chiefly used, the French Company which manufactures it claiming to make about three hundred a day. This Company has made some improvements in it, and also exhibits two-rate meters,

prepayment, and hour meters. It also exhibits the O'Keenan meter, which is of considerable interest, as it is a cheap ampere-hour meter for small consumers; it might be said to be a d'Arsonval galvanometer in which the coil revolves and registers the number of revolutions; it starts with as small a power as one microwatt, and registers as small a current as 5½ per cent. of that of a single lamp; 11,000 are already in use. A modification of the Thomson meter, of some interest, is shown by the Luxsche Works in the German section; the armature is made of three coils like in the old Thomson-Houston arc machine, through which the current flows in series instead of in multiple, as in the Gramme ring form, and therefore the whole armature becomes much lighter, with many attending advantages. The Aron pendulum meter is well exhibited; improved types are shown, including a three-phase meter. The Holden periodically registering meter, which is shown in operation, has several points of interest.

In Class 24 (Electrochemistry) there are a number of fine exhibits, though they are hardly sufficient in number to represent the true state of the art. Among the more important may be mentioned the products of Moissan's classical researches; also his furnace in operation. There are also several carbide furnaces in operation which, together with a very large ozone apparatus for sterilising water, are all shown in the Annexe for Electrochemistry. The Acheson carborundum is shown in the American mining section, and some of the products made from it are exhibited in the electrical section. There are two fine exhibits of the Elmore copper-depositing process, in which the copper is deposited directly as a tube during the refining operation. There are quite a number of exhibits of accumulators, most of which are French, and are all together in one group; there are also several good English exhibits of accumulators. In the French accumulators section there are several which are intended for automobiles, among which may be mentioned the Fulmen, Pulvis, and the Phenix. An electrolytic engraving apparatus for engraving steel dies by means of a plaster of Paris mould saturated with an electrolyte, and lightly pressed against it while the current passes, thus etching away the metal, is shown in operation in the German section. The Goldschmidt process of burning

powdered aluminium with oxides of other metals, producing extremely high temperatures and reducing the metal in very pure form, is shown in operation; it is used commercially for reducing such metals as chromium for the iron industry, and for mending broken iron parts of machines, or joining rails for tramways.

The Three Hundred and Fiftieth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, 25, Great George Street, Westminster, on Thursday evening, November 8th, 1900—Professor JOHN PERRY, D.Sc., F.R.S., President, in the Chair.

The minutes of the Annual General Meeting held on May 24th, and of the Extraordinary General Meeting held on August 16th, 1900, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that these names should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Members—

C. Procter Banham. | F. R. Davenport.
Edward Henry Tyler.

From the class of Associates to that of Associate Members—

Frank Armstrong.
Reginald Henry Tudor Drummond.
Arthur Hattersley.
John Clarence Lyell.
Harold Window Morisset.
Harold Skipwith.
Frederick J. Thompson.

From the class of Students to that of Associates—

William Ernest Few. | Captain Walter John Underwood.
Frank King Westbrook.

From the class of Members of the Northern Society of Electrical Engineers to the class of Members—

A. Lester Taylor.

To the class of Associate Members—

J. A. Gee. | Walter James Hide.
A. Kelly.

To the class of Associates—

Joseph McDermott.

The PRESIDENT: Before the Secretary reads the list of donations to the Library, Building, and Benevolent Funds, I should like to say that Colonel Crompton, who, as you are aware, has just returned from South Africa, has presented to the Institution an exploder used by the Boers for blowing up bridges.

Colonel R. E. CROMPTON: I have carried this Dynamo Exploder from Nelspruit to this room, which is a journey of nearly 8,000 miles, in order that the corps of Electrical Engineers, who are now on their way home, may present it to the Institution. The remainder of the officers and men will be in London within a month from this date, and then, perhaps, a more formal presentation can be made.

At one time during my journey from Nelspruit to Pretoria the Boers attacked the line just after our train had passed, and then its re-capture by the Boers was very probable.

This piece of apparatus may be interesting to you, as we believe it was the identical apparatus which was used by Théron to blow up and destroy property of immense value in the shape of railway bridges, buildings, waterworks and the like. We thought that such a trophy would be more appropriately presented by members of our profession than the usual fragments of shell, rifles, and the like.

The PRESIDENT: I may say we are to have an even more valuable gift from Colonel Crompton during the session—a paper on his experiences in South Africa.

Donations to the Library, Building Fund, and Benevolent Fund were announced as having been received since the last meeting from—

The Astronomer Royal, Mon. C. Beranger, The Harvey Iron and Steel Company, Mr. J. B. C. Kershaw, The Lords Commissioners of the Admiralty, Messrs. Methuen and Co., Professor Spooner, Drs. Squier and Crehore, Mr. W. F. Stanley; Messrs. E. Danvers, H. F. Parshall, W. P. Maycock, J. W. Meares, T. L. Miller, J. Swinburne, Members; Professor J. Epstein, Mr. M. Otagawa, Foreign Members; and Mr. A. Stewart, Associate. *Building Fund*, from Messrs. E. B. Ward, L. J. B. Wall, Leon Drugman, E. M. A. Malek, W. W. Strode, A. A. Crawford,

J. P. Lawrence, J. G. Wilson, J. H. Garratt, C. M. Renton, A. Wray, C. E. Grove, R. Sykes, J. Grant, John Denham, Sydney Evershed, A. Stroh, A. C. Curtis-Hayward, E. Gimingham, W. O. Rooper, T. H. Harrison, W. E. Langdon, C. Faraday-Proctor, T. W. Tischendörfer, E. Mascart. *Benevolent Fund*, from Messrs. Jonas and Colver, Limited, A. E. Whittaker, F. W. Huband, J. W. Smith, Redfern, Nalder Bros. and Thompson, A. C. Cossor, J. W. Barnard, Thomas Sanders, Alfred Arculus and Co., The British Electric Safety Lamp Works, William Rickard, Webb, Shaw and Co., Taylor and Co., T. W. Lench, Limited, The Campbell Gas Engine Company, The China Furniture and Electric Fittings Manufacturers Association, Davis and Timmins, Limited, Le Carbone, Anderson, Anderson and Anderson, Rainsford and Lynes, F. Krasa and Co., Henderson and Walker, Allen Everett and Co., Hawkins Bros. and Co., J. G. Wilson, The Electric Power Storage Company, "Anonymous,"

to whom the thanks of the meeting were duly accorded.

The PRESIDENT: Dr. Silvanus Thompson will now present the premiums to those who have earned them during the last session, when he was President of the Institution.

The "Institution Premium," value £25, to Mr. C. E. Grove Member.

The "Paris Electrical Exhibition Premium," value £10, to Mr. S. Evershed, Associate Member.

Two Extra Premiums, value £10 each, respectively to Professor George Forbes, F.R.S., Member, and Mr. H. M. Sayers, Associate Member.

A Premium, value £5, to Mr. A. Russell, Member, for an "Original Communication."

A Premium, value £5, to Messrs. C. C. Hawkins, Member, and R. Wightman, Associate, for an "Original Communication."

The First "Students' Premium," value £10, to Mr. R. P. Howgrave-Graham, Student.

The Second "Students' Premium," value £5, to Mr. C. B. Nixon, Student.

The Third "Students' Premium," value £5, to Mr. H. J. Humphreys, Student.

The Salomons Scholarship to Mr. R. P. Howgrave-Graham, a student of the Technical College, Finsbury.

Colonel R. E. CROMPTON: The first duty that has been entrusted to me on returning to this country is the congenial one of proposing "That the best thanks of the members of the Institution of Electrical Engineers be given to Professor Silvanus Thompson for the very able manner in which he has filled the office of President during the twelve months,

1899–1900, and for the indefatigable personal attention which he has given to the duties of the office."

It is unnecessary for me to remind you of the valuable services which Dr. Thompson has rendered to our profession, by his writings, teaching, and inventions ; I think you must take this for granted.

It seems only yesterday that I was in Switzerland with that extremely pleasant party over which Dr. Thompson presided with such courtesy and success, and I must remind you that this first and highly successful experiment of an extended Continental tour owed its success very greatly to our President ; it was very fortunate for us that he was a *persona grata* with every one we met in our tour through the towns and works of Switzerland. He was specially gifted by his linguistic attainments and by his power of expressing himself in German so as to be able to speak for our Institution in a graceful and dignified style, which all who heard him felt proud of.

Mr. W. M. MORDEY : I have very great pleasure in seconding Colonel Crompton's resolution. On account of Colonel Crompton's absence from England he has had perhaps fewer opportunities than those who have stayed at home of seeing the work Professor Thompson has done for this Institution. All here know with what urbanity, care, and skill he has conducted the general meetings. But the President of this Institution has much important work to do besides that at the general meetings. His part in our first visit abroad you all know. I need hardly tell you that in committee-room work, and the work which has to be done in organising the arrangements, and dealing with the many matters that come before the Institution, Professor Thompson has also rendered the highest service. I have missed few meetings of this Institution for about nineteen years, and so I have had some experience of our Presidents. Comparisons are to be deprecated, but I think I may say we have had no more successful President than Professor Thompson. I am sure every future President will feel that Professor Thompson has made it a difficult task to adequately occupy the Presidential chair.

If we had more time to-night, I am sure, as your applause shows, you would like to spend some of it in expressing more fully our appreciation of all the services which Dr.

J. P. Lawrence, J. G. Wilson, J. H. Garratt, C. M. Renton, A. Wray, C. E. Grove, R. Sykes, J. Grant, John Denham, Sydney Evershed, A. Stroh, A. C. Curtis-Hayward, E. Gimingham, W. O. Rooper, T. H. Harrison, W. E. Langdon, C. Faraday-Proctor, T. W. Tischendörfer, E. Mascart. *Benevolent Fund*, from Messrs. Jonas and Colver, Limited, A. E. Whittaker, F. W. Huband, J. W. Smith, Redfern, Nalder Bros. and Thompson, A. C. Cossor, J. W. Barnard, Thomas Sanders, Alfred Arculus and Co., The British Electric Safety Lamp Works, William Rickard, Webb, Shaw and Co., Taylor and Co., T. W. Lench, Limited, The Campbell Gas Engine Company, The China Furniture and Electric Fittings Manufacturers Association, Davis and Timmins, Limited, Le Carbone, Anderson, Anderson and Anderson, Rainsford and Lynes, F. Krasa and Co., Henderson and Walker, Allen Everett and Co., Hawkins Bros. and Co., J. G. Wilson, The Electric Power Storage Company, "Anonymous,"

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Thompson has rendered this Institution. They have culminated, but they have not ceased, I hope, in his occupancy of its chair.

The resolution was then put by the President and carried by acclamation.

Dr. SILVANUS P. THOMPSON : I thank you very heartily for this vote of thanks, particularly for the kind, the too kind words, in which it has been moved and seconded. Every President in his turn has to do his duty, and I have tried to do mine. The statistics of the Institution show that we are not yet at our highest point of attainment, for the curve of increase has still an increasing upward slope. It is quite clear that we are making additional progress every year. The fact that in my year of office the increase has been higher than in any previous twelve months, is of course due to the good work that has been done for years past by those who have preceded me in the chair of the Institution, and to the work of the officers of the Institution, the co-operation of the members of the Council, and of the membership generally, working together for the general good. Evidence of this can be seen not only in the statistics of membership but in the facts as to our resources. For example, it is a most gratifying thing to me to have been President during the year when we have added no less than £2,140 to our Building Fund. Of that sum, about £470 was actually subscribed last autumn in consequence of an appeal we sent out ; about £181 is brought in by interest in the stock already invested for the Building Fund, and £1,400 was transferred from the surplus of our general fund about a year ago. The Benevolent Fund in like manner has grown by about £470, of which £30 only is dividend on stocks held for the Benevolent Fund. Further, during the year that has gone by we have had that splendid gift from Dr. Henry Wilde, our Honorary Member, of £1,500 to form a special Wilde Benevolent Fund. We have also been the recipients of a most handsome legacy of £2,000 from our beloved late past-President, Professor Hughes, to found the David Hughes scholarship. All this is evidence that our Institution is making good and substantial progress. Its activities are greater and greater every year ; and knowing the character of the work that is undertaken by the Council and the spirit in which that work is carried out, I, in retiring

from the office of President, am confident that I may leave the chair with the satisfaction, not merely of looking back upon the prosperous year during which I had the honour of occupying it, but of looking forward to future years when this Institution will enjoy even greater success and attain even greater influence. Particularly confident may I feel that the chair is now occupied by one so well capable of maintaining its dignity and its credit, and of wielding righteously, and for the good of the electrical fraternity, its ever-increasing influence.

I have had the pleasure and satisfaction of knowing Professor Perry personally for twenty years, and for twelve years of that time I was intimately associated with him as a colleague in daily intercourse. And I will say this, that no man on earth could wish for a truer friend or a more completely perfect colleague to work with than John Perry, your present President. Therefore I now perform this last duty, on retiring into the position of ex-President, of congratulating you on your choice of my successor.

INAUGURAL ADDRESS.

By PROFESSOR JOHN PERRY, M.E., D.SC., F.R.S., President.

I do not intend to make this in any sense a report of the progress of our Institution during the last or any number of years. I shall not, therefore, give any account of the exceedingly good work done by Colonel Crompton and the active service corps of our Electrical Engineer Volunteers in South Africa. I shall not describe how we *fêted* our American cousins in England and France, nor how they *fêted* us ; nor what a wonderful success accompanied all that was attempted by us or by them or by M. Mascart and our French colleagues, although I cannot refrain from bearing my testimony to the great kindness of the Prince of Wales and the British Commission in so generously lending us the British Pavilion for our great reception and giving us the use of one of its rooms for our office all the time of our visit to Paris.

My brother has tried to get me to introduce to your notice

some novel ideas which have come to us during the last ten years in our business of lighting the City of Galway from a fairly constant water-power using accumulators with a Dowson gas plant stand-by. It has almost come to be a practical idea to produce Carbide of Calcium in wet seasons and utilise it through the gas engine in dry seasons. I was also tempted to discuss the use of large gas engine plant at central stations; and another of several subjects in which I have been recently engaged has been the magnetic effect produced by systems of electric traction. But I have resisted temptation and have chosen a subject which seems to me much more important.

Your president's address is followed by no discussion. He is, therefore, privileged, but his very privileges cause him to address you with a greater sense of responsibility; he may say what he pleases, but he must be very sure that he has the best interests of the Institution at heart; the interests of the Institution as a whole, not the interests merely of a few members, and least of all ought he to think of his own interests. Nevertheless, your president speaks not as an omniscient judge, but rather as a very fallible, very prejudiced one-sided man who, because he has devoted himself to one part of the work of this Institution, is certain to be unfair in his comments upon other parts of the work.

Your past presidents represent in this way all classes of members of this Institution. You have had scientific men, given, some of them to calculation and some to experiment and some to both; men who have advanced the study of pure science. You have had practical telegraph men, civil and military, men cunning in land and deep-sea telegraphy and telephony; men cunning in railway signalling. You have had electrical chemists. You have had manufacturers and users of all kinds of electrical appliances. You have had men who devote themselves to the teaching of electrical engineers, and who fully appreciate the fact that no good teacher ought to be out of practical touch with the profession. And nearly all your past presidents have invented things which are now in practical use.

As each of these men has given you at least one address written from his own peculiar point of view, his prejudices are not likely to have done any harm to members who read

the other addresses. I know, therefore, that you are good-naturedly prepared to give me plenty of rope. I can predict the twinkle of amusement in the faces of some of my friends when they learn that I am about to take up a subject on which we have had many debates. Your attention has just been attracted to the curves showing the numerical growth of our Institution in membership, and this has been marvellous, but I would speak of something more than mere numbers, namely, the *quality* of our membership. In fact, I mean to put before you this simple question: Is electrical engineering to remain a profession or is it to become a trade? Is this Institution to continue to be a society for the advancement of knowledge in the applications of scientific principles to electrical industries, or is it to become a mere trades union?

Of course, at the present time the outside public are willing to regard membership of this Institution as a Symbol of something more than the membership of a mere trades union. During the early growth of any trade, even such a trade as that of the plumber, it was really a profession. And a common trade may suddenly become a profession, if it suddenly begins to develop, as, for example, stone-masonry of a hundred years ago suddenly developed into civil engineering. Electrical engineering has been developed rapidly, so that in the past it has certainly been a profession and not a trade.

Again, we are an institution of engineers, and the general public are willing to class us with other engineering institutions—for example, the Institution of Civil Engineers Now the title M.Inst.C.E. is a professional distinction which represents in civil engineering what F.R.C.S. does in surgery, or M.R.C.P. in medicine. We owe a great deal to our association with, and recognition by, the Institution of Civil Engineers; our meetings are held in its rooms; many of our members are also its members; our proceedings are modelled on its proceedings.

Now this older Institution, governed by the best thoughts of the best British engineers, has laid it down that its associate members, that important class from which the higher class is mainly fed, shall have passed certain specified examinations in pure and applied science.

I am not now suggesting that we ought to adopt this

science examination method of admitting any kind of members to our Institution. I do not believe in the wholesale adoption of methods of working from another society. I am asking you early in my address to remember that this greatest of all professional engineering institutions, governed by practical men full of common sense, knowing the wants of their profession well, insists upon a knowledge of science in its new members. If this recognition of science did not exist anywhere else in the whole world, I say that its recognition by such a thoroughly good professional society as that of the Civil Engineers ought to recommend it to all professional societies.

In Germany an enormous stride has recently been made in the raising of Engineering degrees to rank with the highest University honours. There is hardly one engineer of eminence in Switzerland, France, or Germany who has not passed with honour through the classes of one of their great science Universities.[1] In Great Britain within the last fifteen years not only have great engineering schools been established in all the manufacturing towns, but even in Cambridge University there is one of the best schools of civil, mechanical, and electrical engineering of which I know anything.

Before we think of imitating the Institution of Civil Engineers, we ought to reflect on certain fundamental distinctions between that Institution and our own which at first sight seem to make us less professional.

There is a well-known unwritten rule of the Civil Engineers to which there are only a few exceptions, that no contracting railway or harbour engineer can acquire the title of M.Inst.C.E. I think myself that it is a pity to draw a hard and fast line between consulting engineers and contractors. No doubt it simplifies the labour of the Council in its selection of candidates, but it gives rise to anomalies.

A man who was once a civil engineer because he served a

[1] I understand also that the great unions of manufacturers in *Germany* are about to make facilities for giving a year of real factory work to the Polytechnic students, thus perfecting the German system. In Japan we found great success in requiring students to spend their summer in real shops, their winters at college. In England it may be that we shall prefer to let all apprentices have shorter factory hours than workmen, articled pupils much shorter hours, their masters being responsible for instruction being given in theory.

pupilage under his clever father, and who now is nominally at the head of his father's large practice, the real engineering work being done by many clever employees, this man may be a member. A contracting engineer who shows marvellous ability not only in rectifying the mistakes of the designer of a large bridge or tunnel or reservoir embankment, but shows the power of Lord Kitchener in directing the work of thousands of men so that no man need be idle, and the whole contract goes on like clockwork, and is finished well in the minimum of time, this man is ineligible. Now in our Institution it has been recognised from the very first that manufacturers and contractors and their employees may belong to the very highest ranks of their profession. Of course, I do not mean men who simply receive the profits of businesses, or even men who merely work to obtain orders for themselves. I mean men who are not merely formally but in reality manufacturing or contracting engineers. I mean men who, in dealing with standardised things, design new methods for quick, good, cheap production of such things. I mean men who improve old forms of things, possibly through their paid subordinates. I mean by a manufacturer fit to be a M.I.E.E a man who might act as his own manager, and who, perhaps, has a wider outlook than on mere managerial duties. So long as a contractor or manufacturer is really an engineer, we know that we add to our strength with the addition of every such member.

But consider a contractor who only uses ordinary types of machines or electrical plant in well-known ways, surely he can hardly be said to be in the profession at all. Surely the one thing that differentiates us from mere tradesmen is that we do not follow mere rule of thumb methods ; we think for ourselves, we weigh advantages and disadvantages. If every new installation required the same treatment as existing ones, the engineer would degenerate into a tradesman, and it seems to me that the electrical engineer ought to have a special fear of such degeneration.

In railway and harbour and river and sanitary engineering, in every new job there are new difficulties to be dealt with. An engineer who designs many undertakings and sees them carried out must be a thoughtful man ; he cannot

help keeping himself acquainted with engineering principles, and so he is a professional man. So an architect finds that each new job requires all his experience. Every case that comes before a real physician or surgeon requires a somewhat different treatment from any old case. Every case brought before a barrister requires the exercise of all his past experience. In every case a *profession* implies the necessity for the exercise of all the outcome of one's past experience; because the work one has to do is never the same as any work one has ever done before. And when I say the outcome of past experience, I really mean certain general principles which one has always in one's mind, principles derived from all that one has done or seen or read about.

Electrical engineering is in a curious position. It owes its being altogether to scientific men, to the laboratory and desk-work of a long line of experimenters and philosophers. Even now the work going on in a laboratory to-day becomes the much larger work of the engineer to-morrow. When at length the laboratory experiment is utilised in engineering, we see that there is no other kind of engineering which so lends itself to mathematical treatment and exact measurement. Most of the phenomena dealt with by the electrical engineer lend themselves to exact mathematical calculation, and after calculations are made exact measurements may be made to test the accuracy of our theory. For a completed machine or any of its parts can be submitted to the most searching electrical and magnetic tests, since these tests, unlike those applied by the mechanical engineer, do not destroy the body tested.

Contrast this with the calculations it is possible to make in other kinds of engineering. The pressure of earth against a revetement wall is possibly 200 or 300 per cent. greater, or 50 to 70 per cent. less than what we imagine it to be in what some limited men call theory. We use factors of safety 5 or 10 or more on all kinds of iron structure calculations, because we are aware of our ignorance of a correct method of dealing with the problems. The civil engineer never has exactly the same problem as has already been solved. In tunnelling, earthwork, building, &c., in making railways and canals, he is supremely dependent on the natural conditions pro-

vided for him: the configuration of the surface of the ground, the geological formation, the structural materials available in the neighbourhood. The story of how the engineer has to study the endlessly different ways of interaction of water and sand and gravel is told by the troublesome bars at the mouths of rivers all over the world, by the difficulties of coast and river-bank protection, by the failure of sea walls and piers. But why should I make a catalogue of the different kinds of work done by civil engineers? Every one of them needs the exercise of general scientific principles due to much experience.

Now of all such natural difficulties the consulting or contracting electrical engineer is greatly independent. Give him a source of power and tell him what is to be done; whether he is to light a town or a building, whether with arc or incandescent lights; whether he drives a stamp mill near a mine or a pump, or a machine tool, or a spinning frame, the electrical part of the work is carried out in much the same way. Natural conditions affect him mainly in the cost of transport of his materials and the cost of labour. He can make in an easy way the most careful calculations as to the best arrangement of his conductors and machines to give maximum economy, and except for this easy calculation his work is that of a mere tradesman. He is practically independent even of the weather. There are, indeed, some of us who grumble that this easy calculation is not made easier still, who prefer to make arithmetical guesses rather than exact calculation, because perhaps we like to see a little uncertainty introduced into the problem to make it more like a problem in civil engineering. I want members to see clearly that as time goes on, as our electrical engineering work gets more and more cut and dried, the man who loses the power to calculate, who loses his grip of the simple theory underlying our work, must sink more and more into the position of a mere tradesman who has no longer the right to call himself an engineer.

An electrical engineer must have such a good mental grasp of the general scientific principles underlying his work that he is able to improve existing things and ways of using these things. It has become the custom to call this *theory*, and I suppose I must follow the custom. I should

prefer to call it *Science*[1] or *knowledge*. Do you remember Huxley's definition of Science? "Science," he said, "is organised common sense"; and this is really what I mean. Well, calling it *theory*, the man who is permeated by theory, whose theory is so much a part of his mental machinery that it is always ready for practical application to any problem, he is the real engineer. But you must not mistake me in this matter. Eighty per cent. of the men who pass examinations in mathematics, mechanics, and electricity have very little of this theory. Fifty per cent. of the writers of letters in the engineering journals in which mathematical expressions occur have almost nothing of this theory in their possession. It is unknown to foolish men. Books alone, lectures alone, experiments alone, workshop experience alone cannot teach this theory. The acumen of a Q.C. may actually prevent a man from acquiring it. A man may have much of this theory, although he may never have listened to lectures, although he may dislike the sight of a mathematical expression. I have known men who might be called illiterate to possess much theory. I have known many men who might be called good *electricians* who are almost wanting in the theory necessary for the electrical engineer.

I am speaking only of theory. Of the other qualifications for an engineer I need not here speak; they are present to the minds of all of us. A man may have any amount of knowledge; he may know how to apply his knowledge, and yet he may not be able to apply the knowledge from a want of engineering *character*.

The engineer must be a real man; he must possess individuality, the power to think for himself. He must not be like a sheep, knowing only enough to follow the bellwether. Over and over again in the last thirty years have some of us given our students much the same sort of advice

[1] What Doll Tearsheet said of the word "occupy" we have to say of the word "Science." It is used by many people out of its proper meaning and then condemned, so that one is getting afraid to use it. In Prof. Fitzgerald's splendid inaugural address to the Dublin Section of this Institution he says: "As has recently been pointed out to me by Dr. Trouton, it would be impossible to say the same contemptuous things of *knowledge* as are said of *Science*. In Germany the word used, 'Wissenschaft,' is the one corresponding to our word 'knowledge,' and there nobody of any sense could say that 'knowledge is all humbug,' as is here often said, and still oftener thought, of 'Science.'"

that Baden-Powell gives to scouts in that excellent little book of his. If any of you have not read that book you ought to buy it at once, and you will there find that if a man is to think for himself he must possess all kinds of knowledge, he must be constantly picking up new kinds of knowledge.

Nobody can limit the value of any kind of knowledge, but still one may say that certain things are probably more important than others. To gain what we call "theory" a good general education is most helpful — mathematical knowledge is very helpful; laboratory and workshop experience are extremely helpful. There is one qualification which the electrical engineer must have and without which all other qualifications are useless, and if a man has it no other qualification is supremely important, and this absolutely indispensable qualification is that a man shall love to think about and work with electrical things. He must like these not because of the money he can make through electrical contrivances, nor even, I think, because of the name he may make before the world—this would be mere liking or cupboard love which has no lasting quality. So long as we have men in this country who have the true love for scientific work of which I speak, so long shall we have a real profession of electrical engineering, for such men are always scheming new contrivances and improving old ones and utilising the services of all helpful people, and especially of capitalists. When we have reached a state in which nobody schemes new things because the existing things are perfect there will no longer be a profession of electrical engineering. Of all ideas surely that of having reached *perfection* is most hateful: the idea of exact knowledge, that nothing is unknown, that there is no need for thought and therefore that to think for oneself is a sin.

And so, although we are all agreed that much standardisation in our contrivances and methods is absolutely necessary for our competition with other nations, we must follow the Americans in this matter and take care that it does not destroy invention. Of course when things are really standardised, when we have our perfect Mauser rifle or dynamo or locomotive or traction engine or electrically driven stamp mill, a Boer can buy or even manufacture them if he has money, and he can use them as well as, or possibly better than, we can. But he is not an

engineer. He uses things after the engineer has done his work upon them. A stoker, a common engine-driver, the guard of a train, these are not engineers. You must have noticed that the American engineers, who surely deserve the character of being practical idealists above all other engineers, are the men who are most imbued with notions of standardisation which lead to cheapness of manufacture, and they are also the men most alive to the necessity for occasional extensive scrapping of types of machinery when they become even a little antiquated.

Our chiefs, the men who run us all, our real men at this Institution, may be called Practical Idealists. They have imagination and judgment and individuality. They have the imagination and enthusiasm of inventors, and yet they are more than inventors, for they can estimate the worth of their own inventions and control their imaginations. They are ready to receive all new ideas, they welcome all new things, and yet they are not carried away. They are radicals and yet they are conservatives. They have what Mrs. Beecher Stowe called *Faculty*.

A strong imagination well under control, surely it is the greatest of mental gifts. I look round me and wonder how many of us really have it; and how many of us are only dull men, who scorn novels and poetry, who live utilitarian, material lives, whose aim is merely to make money through electricity, who love it not for its own self, who cherish their "tuppeny-ha'penny-worth" of theory because it is sufficient for their immediate wants. Why, even the writers of leading articles in the daily papers can talk of the wonders of electricity and what may yet come to pass; and yet we who make machines and use them and switch the marvellous thing on and off and take all sorts of liberties with it—we are like Calibans oblivious of the wonders of the fairy isle—like soulless priests making a living in the temple of Isis—like Aladdins who rub our lamp only to get the necessaries of life.

Twenty years ago some of us were laughed at for our optimism, and yet everything that we declared then to be doable has now actually been done by engineers, except the thing which was then and is now declared to be the supremely important thing, namely, the electric consumption of coal. We say now, as we said then, "The applied

science of the future lies invisible and small in the operations of the men who work at pure chemistry and physics." And think of the wonderfully rapid rate at which laboratory discoveries have been made in the last eleven years, and how as the years go on they become more and more numerous; and yet many of us plod along with our work seeing no farther than our noses. A year is now more pregnant with discovery than a hundred years used to be, and yet the protective stolidity of our ancestors is upon us and we think of the latest discovery as if it were really the very last that can be made. A thousand men are measuring and trying new things in laboratories all over the world. Some of them plodding and soulless; others of them with imagination and clearness of vision. Do you think that nothing is to come from all that work?

And is it not one of the most important functions of the engineer to do as Mr. Marconi has done, to convince capitalists ignorant of science that if the successful laboratory experiment is tried on the large scale it must also be successful? And are we going to leave all this pioneering work, with all its possibilities of great gain, albeit with possible loss, to foreign engineers, when in most cases the scientific discovery has been made in England? Are we so lacking in the hope and faith which are born of imagination and science? And must we in the future as in the past have to rely upon the influx of the clever foreigner like Sir William Siemens? Must we, Boer like, always depend upon our Uitlander population, Fleming and German, Hollander, Huguenot and Hebrew, for the development of our natural resources?

Some of the best engineers I know are so exceptional that one must class them with geniuses; they have faculty and character, and so they have become engineers even under the most unfavourable circumstances. They have passed through ordinary schools and yet developed common sense. They were pitchforked into practical work, and their liking for the work as well as some curious kind of instinct led them to pick up all sorts of knowledge which have become part of their mental machinery. They continue to pick up new kinds of knowledge when these become necessary for their professional work. Unfortunately these men do not realise

how exceptional they are, and they advise boys to go direct from school into works. They forget that the other 99 per cent. of men treated in the same way as themselves can only become the hewers of wood and drawers of water to real engineers. Treated in this way average boys are just like so many sheep: they learn just what seems absolutely necessary and no more; their acquaintance with the scientific principles underlying their trade is a hand-to-mouth knowledge which becomes useless when their trade undergoes development.

In 1867 I was an apprentice, and when in the drawing office and pattern shop I remember well how I was chaffed for studying such a non-paying, non-practical subject as electricity. When I published my first electrical paper in 1874 before the Royal Society, and even for some years afterwards, the real students of electricity in England could be counted on the fingers of one's hands. Many of us remember the first Gramme magneto machine that came to this country, a scientific toy, in 1874. How many engineers dreamt that a great new branch of engineering had been started? Even in 1878 engineers were as a rule quite ignorant of electricity, and since then every year, although newspaper writers have talked largely of the age of electricity, the men actually engaged in electrical industries have acted as if the greatest of changes were not perpetually going on in it. To be left behind, or to become camp followers, children of Gibeon, this is the usual fate of the men who scorn theory. In 1882–4 we used to have to pay men £200 and £300 a year because they had a slight knowledge of electrical matters. In 1884–6 these very men were not worth twenty shillings a week, they were weeded out of the profession and their places were taken by men of better knowledge. Two or three years after,, these better men were again found to have been weeded out, because men of still better knowledge were available. And so it has gone on ever since. Men learn just enough to get posts; they settle down in these posts and scorn theory. They actually forget what little theory they once did possess. They know a great deal about existing machines, but presently they discover that improvements have been going on, and that they no longer have a right to say that they belong to the engineering profession. In every year one has told

men, "You will be left behind. See A and B and C. I told them three years ago, when their names were in everybody's mouths, that they would be left behind like their predecessors, and they laughed. Now I tell you and you laugh, and you also will be left behind. Yes, I know that you get a good salary or large fees, and your head touches the sky. Nevertheless, because you neglect theory and the simple mathematics by means of which theory is made available in practical problems, you will have to take a back seat presently, for our profession is in its early youth and is growing rapidly."

Remember that I do not now refer to the few exceptional heaven-born engineers who, in spite of bad training, do manage somehow to pick up the necessary knowledge. I speak of the average men, many of whom are now living in the same old fool's paradise. They know enough for present needs; they scorn the simple principles which underlie all our work; they scorn the easy mathematics by which these principles are most readily employed in practical problems; they will have their reward.

Just think of what is occurring at the present time. In England we have cheap coal, and it can be carried easily. In Switzerland and other countries where there is no cheap coal the water-power had to be utilised and power had to be transmitted great distances electrically. This needed high voltage, and as it is difficult to get high voltage with direct current machines, alternating currents were used, and on account of motor troubles multiphase working has been introduced. What a revelation it was to almost all of us, that visit of a year ago to Switzerland! We saw enormous schemes of lighting and traction and power. We saw electric trains driven by distant waterfalls sandwiched in among ordinary trains keeping proper time on working railways. We had known that there were great schemes carried out in Germany and America and other countries, and yet all the machines were quite unfamiliar to us. We were very much like what engineers of 1870 would have been if suddenly brought into a generating station. Is it not a fact that some of us, said to be eminent and thought to be practical, asked questions and made remarks which showed that we did not know the most elementary principles of three-phase working. Is it

then any wonder that the traction schemes now being developed in England, on lines that are certainly not the best for this country of their adoption, are altogether dependent on the use of foreign electrical machinery and employ foreign electrical engineers? I am not putting this altogether fairly, for municipal procrastination has prevented our development, and yet I am not putting it altogether unfairly. We know too little theory.

I am afraid that just now we are in a rather tight place. I would give something to know how we in this room are going to get acquainted with what some people rightly or wrongly consider the most important kind of modern electrical engineering. Our usual way of learning is by actual handling of things. But if the millions of pounds' worth of machinery coming to England every year is all foreign and is used mainly under foreign superintendence, our usual method of study is made very difficult. True there are American and German, and indeed a very good English publication which would give a knowledge of the theory, but not, I think, to the average English electrical engineer. I know of many men 25 to 40 years of age who seldom come to our meetings, and who say they are silent in discussions because they cannot be understood; perhaps these men will find a way to save us all from being left behind. There is much more that I might say in this connection. An individual Englishman may be left behind other Englishmen, and all English electrical engineers may be left behind the rest of the world, but all electrical engineers of the world may even be left behind other appliers of science. It is not merely that the incandescent mantle of the gas engineer is improving and necessitates improvements in our filaments, but in spite of the flourishing conditions of our factories just now, I could give many other illustrations of how we shall all suffer if we do not keep adding to our knowledge. Twenty years ago, when giving some lectures in Clerkenwell to workers in the then flourishing watch trade, I ventured to prophesy the decay of that trade. But I am afraid that the case of Jonah and Nineveh is the only one in which prediction of disaster led to reform. I venture on no prophecy therefore, because it might harden your hearts.

Much of the evil we suffer from is due to our average

young men being pitchforked into works where they get no instruction, as soon as they leave school. If ordinary school education were worth the name, and if schoolmasters could be brought to see that we do not live in the fifteenth century, if boys were really taught to think for themselves through common sense training in natural science, things would not be so bad. But the average boy leaves an English school with no power to think for himself, and with less than no knowledge of natural science, and he learns what is called mathematics in such a fashion that he hates the sight of a mathematical expression all his life after.

And what is the result? English engineers do make a wonderfully intimate acquaintance with the machines and tools that they work with, but when it comes to the manufacture of new things they do it by fitting and trying, by quite unnecessary expenditure of money through trial and error. A machine is made and tried and then another better one, until a good result is arrived at. And this method did well enough in the past and would do well enough in the future if only we had not to compete with foreigners who can really calculate. It is not all smoke; there is a real danger in this foreign competition unless we mend our ways. There is an absolute necessity for great change in English ways; but there are so many people interested in the maintenance of old methods of working; so many people who think they will lose their bread and butter if a change takes place; so much capital, scholastic and other, invested in our old machinery; that it takes a catastrophe to produce changes. Much of the strength and weakness of England has always lain in her conservatism. We have been talking of *standardisation* of machinery lately, so I may say that things have been standardised in England for a long time. Now to get all the good effect of standardisation it is occasionally necessary to go in for wholesale *scrapping*, and it is this scrapping part of the business that we dislike in England. We here all know that the District and Metropolitan railways might have been worked electrically years ago just as easily as they will be when we are allowed to begin upon them, but of course the scrapping of a lot of steam locomotives was a serious thing. The loss of experience to English

electrical engineers, because of this hatred of scrapping, is leading to other incalculable losses. I understand that the whole generating and line plant—the whole machinery of the Boston tramways—has been scrapped several times since they first were driven electrically. Japan has scrapped all her old civilisation just as France did. During the century now dying Germany has made the most sweeping changes in her land and school legislation, and indeed in everything. England and Spain and China, how they differ in this respect even from England's own colonies.

Of course it may be said that English customs have grown during centuries; they are well tried and there is no pressing need for sudden alteration. I quite agree, but unfortunately this very perfection and fitness of our customs have bred in us a want of flexibility, so that in cases where a sudden change is really necessary, we are disinclined to make the change merely because it is a change and for no other reason.

No one has ever heard me speak of the decadence of England. When the greatness and the wealth, the manliness and the strength, the healthiness and good life of England are shown forth to the as yet ignorant world in all their magnitude there will be some astonishment. But it is our duty to keep up our high standards. We must change what is bad when we know it to be bad, and not let bad things[1] continue to exist, parasitic growths, maintained because on the whole we are strong and healthy. You will perhaps think that this is a very serious exordium when I tell you that I have introduced it all on account of the state of mathematics in our profession. I feel a sort of degradation every time that I hear a successful, clever old member of this Institution sneering at mathematics. There is a plausibility about his statements; he himself has been very successful in life without much help from mathematics; but indeed his sneer is doing a great deal of harm to the younger members who admire his success, who forget that he has

[1] Such as our wretched system of weights and measures. Oh young America and Australia, is it wise to waste a year of every child's life, and years of the life of every business man, merely because we do it in England? You get many of your pedagogues from us, and of course they say that without cwts., qrs., and lbs., and Latin declensions and Euclid, the mind cannot be trained. Do you believe them, or are you with open eyes making a great sentimental sacrifice?

succeeded in spite of, and not because of, his neglect of mathematics.

Our knowledge of electrical phenomena must be quantitative to be of practical use ; we must be able to calculate. Mathematics is the science of calculation, and we must therefore be able to employ, and we all do necessarily employ, less or more mathematics every hour of our professional lives. The draper and the grocer and the housekeeper merely need arithmetic. Everybody now knows some arithmetic. Everybody can add and subtract and multiply and divide, and keep accounts in some simple sort of way. This is due to the fact that arithmetic is no longer taught in the old Greek method with its twenty-seven independent characters (for our ten figures), the study of which required a lifetime, so that only old men could do multiplication, and they not only needed many hours to do one easy bit of multiplication, but declared that if the art were not practised every day it could not be remembered. Reading and writing and ciphering are now taught to everybody. It used to be that only learned men and philosophers could read, write, and compute. You will remember the charge that was brought against one of Shakespeare's characters, who was said to possess mere bookish theory without practical knowledge. "And what was he ?" "Forsooth a great arithmetician." Nowadays, when everybody can compute, we should say of the possessor of mere bookish theory, "Forsooth he knows the calculus."

For in mediæval times things were taught in such a way that only a few men had a chance of knowing how to read, write, and cipher. We have been compelled to change all that, the pedagogue has by compulsion given up his mediæval methods of teaching in these things, although in all other matters he retains them. But a time has come when we see that ciphering is not enough mathematics for us to be familiar with, we need a little algebra, we need co-ordinate geometry, we need the differential and integral calculus. The pedagogue tells us that we must follow the orthodox course of study, which takes many years ; and some of us, many of us, who have followed the orthodox method find that we have spent so much time and mental power upon it and its thousands of unnecessary tricks and contrivances and philosophy, that we can take in no more

ideas. We cannot utilise our mathematics on engineering problems because we are too old and tired and *blasé* to comprehend these problems. Nevertheless we are the only people who know mathematics, and so we publish volumes of unmeaning and useless disquisitions on problems that we do not understand. Or we know just enough mathematics to be able to show our ignorance to experts, but quite enough to impress engineers with our knowledge ; and we know just enough about engineering problems to show our ignorance to engineers, but quite enough to impress mathematicians, and what we publish is merely as the crackling of thorns under a pot.

As for the man who does understand electrical problems, he remembers that there was a something called a study of mathematics at his school, that he did pass certain examinations with much difficulty and tribulation, that the subject had no real meaning to him even when he was supposed to know it, and he now hates the sight of anything that looks like mathematics.

I tell you, gentlemen, that there is only one remedy for this sort of thing. Just as the antiquated method of studying arithmetic has been given up, so the antiquated method of studying other parts of mathematics must be given up. The practical engineer needs to use squared paper. What is the use of telling him that he has taken an unauthorised way to the study of co-ordinate geometry, that he cannot approach it except through Euclid and modern geometry and geometrical conics and algebra and trigonometry. He says the youngest child can be made to understand diagrams on squared paper.

So again the idea underlying the calculus is one that every child, every boy, every man possesses and uses every day of his life, and there are useful methods of the calculus that might be taught quite quickly to boys, and which it would be a pleasure to boys and men to use continually in all sorts of practical problems, but of course the subject of the differential and integral calculus is one that must come at the end of a long course of what is to the average boy utterly uninteresting and unmeaning mathematics. Indeed, the average boy never reaches the subject, whose very names, differential and integral calculus, are enough to drive him frantic.

Yes, the schoolmasters say that we must follow the mediæval rules of the game, and all sorts of fine things are said about them, but as a matter of fact we only need to bring a little common sense to bear upon schoolmasters. At present most of us stick to our arithmetic as a safe and well-tried friend. We compute after the manner of the draper and grocer and housekeeper. In finding out what is the best size of conductor, or armature winding or core, or iron and winding of a field magnet, we calculate by mere arithmetic for one size and then for another; perhaps we have weeks of arithmetical computation before we find the right size of thing to use, and we cannot frame general rules. And some foolish person who knows a little mathematics, works at the problem (as we ought to be able to do but are not) and he frames a general rule and we laugh at it, and sneer at mathematics because he has probably left out of account the most important consideration. We know that the result is wrong but we cannot say why it is wrong.

Then there are some far-reaching, labour-saving ideas that we simply cannot get into our heads at all, we cannot comprehend them. Am I sinning against the rule as to good comradeship which exists here if I say that some of us are ignorant of the most fundamental fact regulating economy in arranging sizes of conductors? Suppose we find the total cost of installing a conductor of a certain length, using one square inch section of copper. We do the same thing for other sizes, and we plot total cost and weight of mere copper on squared paper. I do not care what system we adopt if it is the same system for all sizes, and if we buy our materials from the same manufacturers and use the same kind of labour, our points will lie very nearly in a straight line on the squared paper. Hence increased cost will be proportioned to increased weight of copper, and, indeed, increased total cost will be like the mere increase in the cost of copper, taking a slightly higher price of copper per ton. Some of us, ignorant of the elementary mathematics involved in the problem, think that the mistake has been made of assuming that the cost of an installed conductor is merely the cost of the copper in it, and of course we must feel that it is too absurd a mistake not to be laughed over. With an elementary knowledge of mathe-

ideas. We cannot utilise our mathematics on engineering problems because we are too old and tired and *blasé* to comprehend these problems. Nevertheless we are the only people who know mathematics, and so we publish volumes of unmeaning and useless disquisitions on problems that we do not understand. Or we know just enough mathematics to be able to show our ignorance to experts, but quite enough to impress engineers with our knowledge; and we know just enough about engineering problems to show our ignorance to engineers, but quite enough to impress mathematicians, and what we publish is merely as the crackling of thorns under a pot.

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matics our mistake would be impossible, and without such a knowledge the clever electrical engineer is constantly discovering mare's nests in the investigations which he criticises.

I know of long misleading accounts of the results of good experimental observations which might have been described in a few clear words by the aid of elementary mathematics. I know men who spend on a particular problem ten times the amount of worrying thought that would enable them to master the easy mathematics that includes all such problems. Quite recently one of our most eminent members declared to me that he had not really grasped the reason for small economy at a power station when there is a small load factor until he studied the common sense mathematical form which has been given in a recent publication. And yet he is a man who has heard much, and read much, and talked much on this subject.

Every electrical engineer has a correct idea of how a transformer acts, or how the E.M.F. in one of the coils of an armature of a direct current or other generator, or, let us say, a rotary transformer, changes during a revolution, and how the E.M.F.s of all the coils are combined to produce currents in the external circuits. But through how much mathematical tribulation must most of us have passed from our state of ignorance to our present state of knowledge! It is no wonder that we are disinclined to the study of a new phenomenon which seems as if it might lead us through the like tribulation. The tribulation is least because it is suffered only once if we first learn the Calculus method which underlies all our work; it is greatest if we get it up in a completely new-looking form in every new problem. I speak now of what is most difficult in our study, for there is thought required in applying the Calculus method. Thus, for example, in multiphase work at the present time the best mathematicians wonder how it is possible for easy calculation to be made in such a subject. What we want just now is that an electrical engineer acquainted with three-phase current phenomena should be so much a master of ordinary easy mathematics that he has a chance of discovering a very simple way of putting the matter before us. At present calculation is easy but tedious, and, indeed, repellent; but I am perfectly certain that a

competent man might quickly invent methods of calculation which are not only easy, but short and thinkable. Mathematicians with the requisite electrical knowledge, again, may be lacking in sympathy and humour. I know a book of more than three hundred large pages on ordinary alternating currents, and all the information in it is given far more simply in two pages of another book with which some of you are acquainted. Possibly, just now, mathematicians who are electrical and who have common sense have too much other work to do, and we must wait their leisure.

The fact is, mathematics ought to be the natural language of the electrical engineer, and at present it is a foreign language; we cannot read or write or think in it. We are at the beginning of our development, like monkeys whose necessities have increased faster than their powers of speech.

Some of you are aware that a new method of teaching mathematics has recently been introduced by the ever-to-be-praised Science and Art Department in nearly all evening classes in science schools throughout the country.[1] I wish I could say that there was a prospect of its being introduced in all schools, for it seems to me that this would lead to the result that all young men entering works would be masters of that kind of calculation which is most important in electrical engineering; not merely a few men having this power, but the average men, just as average men can read and write.

I am addressing engineers, men who utilise the results arrived at by scientific workers, men whose profession is applied science. But surely if we are to apply the results arrived at by scientific men, if the laboratory experiment of to-day is to be our engineering achievement of to-morrow, we ought to be very much alive to all that is going on in the scientific world.

All men ought to be far more alive to the importance of scientific work. On the psychological side, it is perfectly exasperating to me to see how few are the men who know that Darwin has given a key to almost all the great philo-

[1] See summary of Lectures on Practical Mathematics; also the Science and Art Directory, and the Reports of Examiners on the Science Examinations of 1899 and 1900, all published by the Education Department, South Kensington, S.W. The reforms now advocated in mathematical and science teaching are all clearly described in a paper read before the Society of Arts in January, 1880.

sophical problems of antiquity, and that there is a great mental development accompanying the more evident engineering development now going on in the world. Again it is the fault of our methods of education that all our great men, our most important, most brilliant, best educated men, our poets and novelists, our legislators and lawyers, our soldiers and sailors, our great manufacturers and merchants, our clergymen and schoolmasters, should remain so ignorant of physical science, the application of which by a few men not ignorant is transforming all the conditions of civilisation.[1] But of all men just think what it means for engineers to be ignorant of science, or neglectful of its new developments, and of all engineers think what it would mean if electrical engineers sinned in this way.

Except ours, all other branches of industry have taken thousands of years to grow. There were bridge and hydraulic and sanitary and harbour and river engineers in ancient Rome, and such engineers existed thousands of years before the first papyrus was written in Egypt. But no Assyrian tile or Egyptian hieroglyphic or relic from a tomb indicates that telephones or electric motors or electric lights existed before our time. No gradual improvement in our methods of conquering nature led up from small beginnings in our electrical engineering. Our profession has not grown during thousands of years of time like other professions. It has sprung suddenly, full grown, from the new spirit which is going to rule the souls and bodies of men, the spirit of research in pure science. The new spirit puts knowledge, mere knowledge of nature, as its highest aim. The scientific student knows that all sorts of good must come to mankind from his studies; all sorts of scientific knowledge are sure to be utilised by engineers, but in the pursuit of science the usefulness and utility of the result are of no importance. And are we—we who have received the first-fruits of the labours of scientific men, we the first-born spoilt children of the great parent of all that is to come, we who form the foremost files of the present time—are we going to turn upon our beautiful young mother and say she is useless and ugly, and she hinders our money-making, and that we are willing to kill her for the sake of the burial

[1] See articles in *Nature* of July 5th and August 2nd.

fee? Thank God that is the spirit of only a few of us. Have we not as an Institution gone to great expense in the publication of *Science Abstracts* in partnership with the Physical Society? That publication has been and continues to be of the very greatest value to all students of pure and applied science who read our language, for it tells them the results of all the scientific work now being done in all parts of the world. And even if some of us do not read that useful publication, do we not know that it is there to read if we like? Do we not know that it is a symbol of our redemption from the yoke of the Philistine? It is one of many signs that in answer to the question which I have asked in this address, we can truthfully say that we are professional men, that our profession has promise of enormous expansion and improvement, and that we are not likely to become mere tradesmen.

I am afraid that you will think that I have a personal interest in putting before you the claims for consideration of the pursuit of pure science, because you know that I am trying to defend Kew Observatory from imminent danger. In truth I have no interest in this matter unbecoming a president of this Institution. For two years I have been trying to reason with traction engineers. Like many other electrical engineers these gentlemen desire to use uninsulated return conductors. If they do so near a magnetic observatory certain records of terrestrial magnetic disturbances are quite spoilt. At Potsdam this sacrilege has been forbidden. At Washington, Toronto, Capetown, and most other important places the magnetic records have already been rendered useless. Professor Rücker and I were asked by the other members of the Committee of the Royal Society which was in charge of the Kew Observatory to defend Kew, and with the help of Her Majesty's Treasury we thought we were able to insist upon the use of insulated returns in all undertakings authorised by Parliament where harm was likely to be inflicted on Government observatories. I may say that the scheme designed by Mr. Clifton Robinson for using an insulated return conductor in the working of the tramways of the London United Tramways Company, in consequence of our action, was a thoroughly good scheme which it gave one satisfaction to look at, not ugly and not expensive. It

seemed to me a fit scheme for any tramway system, however complex, in which overhead conductors are used. You are aware that for an electric railway or for a tramway where an underground conduit is employed, it is in every way better, and it is in a large scheme actually cheaper to use an insulated return. We felt therefore very happy, for magnetic observatories seemed quite safe from interference. We were, however, mistaken, for the only clause which we have been able to get inserted in all Parliamentary authorisations of undertakings, leaves it to the Board of Trade to substitute other methods of protection than the insulation of the return conductors in cases where these other methods seem to be sufficiently good for the protection of laboratories and observatories, and this is why the Board of Trade appointed the Committee which met on the 31st of October probably for the last time.

Professor Rücker, Professor Ayrton, and I have made many tests on the magnetic disturbances produced by tramways and railways, particularly by the Stockton tramways and by the Waterloo and City Railway, and we have had many meetings with the traction engineers, but nothing has yet been decided.

I mention this matter, which has given great anxiety to scientific men, because I am afraid that some of you may think when you hear of it that I have been acting against the interests of the electrical industry. I beg to assure you that I have been acting in your best interests. As an electrical engineer I ought surely to regret the use of uninsulated returns even if we leave Kew Observatory out of account. Suppose we do not now insulate our returns. Electricity will certainly return by gas and water pipes, and the amount of harm done to those pipes is merely a question of time. Because of the ignorance of legislators and gas and water companies, nothing is said just now, but will nothing be said at the end of ten or twenty years when pipes are found to be eaten away everywhere? And if by a slight increase of expense, or rather, as I think, actually no increase of expense, but merely a little increase in inventiveness and common sense on the part of electrical engineers, this evil may be entirely prevented, surely it is in the interests of all of us that insulated returns should be insisted upon. But even if we do not insist on insulating

the returns in all systems, surely something may be said for the giving of this protection on lines near such a magnetic observatory as Kew. Even the magnetograph records now being made have been continuous for forty-five years, and if Kew is interfered with no sum of money can compensate for the interference; for if the Observatory were removed the future observations would have no link with the past.

An engineer in this room declared that it seemed to him an injustice to hamper the progress of electric tramways "for the sake of making observations that never have given, and never may give, to the world any important results." Now, it is not so much on account of Kew that I object to this sort of observation, as for its general spirit of antagonism to scientific research.

There is no doubt that the answer to the old question which Gilbert might have asked three hundred years ago, "What is the cause of terrestrial magnetism?" is very jealously hidden from us by Nature. The earth probably contains much iron, but its great internal heat seems to forbid our imagining the iron to be magnetic. The assumption that a negative electric charge on the rotating earth will explain things, requires such an enormous charge that this assumption has been discarded. There are annual and diurnal variations of a fairly regular kind; there are storms which have some relation to the Aurora Borealis, to sunspots and to earth currents. There are small sudden changes which seem to occur almost instantaneously all over the earth. Observations of these things may be useless from some points of view, but scientific men have been and continue to be willing to give up time and much money for this object. Utilitarians had to be cajoled through superstition to allow observations of the stars to be carried on in ancient times, and we have no such cajolery to offer. We simply say that it has been through this sort of useless-looking method of working that all our progress in science has come.

Engineers descended from men who sneered at Cavendish and Franklin and Volta and Oersted and Ohm and Faraday, are you who utilise the results of the work so sneered at and pile up fortunes in consequence of it, are you the men to sneer at and ridicule the scientific work of the present day because it seems to you useless?

Tell us a better method of observation; give us better suggestions as to what these magnetic phenomena may mean; but the past record of scientific observation enables us to laugh at you when you say that magnetic observations may never give the world any important results. Was Nature ever so open and yet so closed about a secret as she is about this one of terrestrial magnetism? Was there ever one whose revelation promised so much? How very little we know of electricity and magnetism! Does the mere motion of the earth, taking no account of electric charges at all, cause it to be magnetic? Almost anything is on the cards. Surely I need not appeal to your cupidity, but it is quite possible that our knowledge of this secret may enable us to tap a tremendous store of Nature's energy.

Gentlemen, this is not a trades union, and it is not a society for the furtherance of pure scientific research, but it is a society of professional men who recognise the past services of scientific observers with gratitude and respect, and hope for greater ones in the future. And shall it be said of us that our gratitude is not greater than that of Judas, to whom indeed thirty pieces of silver was doubtless a large sum; that "we have given our hearts away a sordid boon;" and that as to our future hopes we are willing to sell our birthright for a mess of pottage?

Professor GEORGE FORBES: I am much gratified in being permitted to propose "That a hearty vote of thanks be offered to Professor Perry for his most interesting address, and that with his permission the address be printed in the Journal of the Proceedings of the Institution." I think you will all agree with me that you have a President who has shown by the splendid address which we have just heard that he is a man who can form his views in an independent spirit, that he will bring them forward at the right time in an effective manner, and has no fear of their being pleasing or displeasing to anybody in the world as long as he feels he ought to put them forward. As long as we have such men among our body he need have no fear that our engineering will fall behindhand. We shall, so long, have men who will have the boldness, the imagination, and the spirit to carry out new engineering works in the face of the world. I have seldom listened to a more interesting

address than the one that is concluded, and that has been only too short. There is a great deal that Professor Perry has kept back that he can still produce on the same strain, I am perfectly sure. At the same time I am sure that each one of us here has found much in the address which he would like to argue out with Professor Perry quietly over a table. This is not a fitting occasion, however, to argue the various points, but there is no doubt that every single point which has been raised by Professor Perry is one worthy of discussion, and one that each of us would benefit by thinking out thoroughly for himself, and seeing it in the new light in which it has been put before us by Professor Perry. He has told us that the three classes who are necessary to the furthering of our profession are in danger of falling behind—the consulting engineers, the manufacturers, and the capitalists who own the plant. I think we must all feel that there is this danger, and that if we do not bestir ourselves we shall be running a serious risk of being left behind. I could say a great deal of the conclusions one has arrived at on these points, but this would not be the time to do so. I certainly agree with a great deal of what Professor Perry has said on these subjects, and on certain others I hold different views which I should be very glad to talk over with him some other time.

I think it augurs well for the state of the profession in this country that the address which we have heard has been listened to, not only with such rapt attention, but with such manifest approbation by so large an audience of engineers here. In the earlier days of electrical engineering I do not think that Professor Perry would have been applauded so much when he spoke about the benefits of theory. The period, however, is past now when engineers despised knowledge, when it was the commonest thing in the world for an ignorant man to brag about it and say, "Oh, I am not a theorist; I do not know anything about theory. I am a practical man." What an assumption for any man to claim for himself such a splendid title! The practical man is the man who knows everything, and who has imagination, and resource, and the readiness to apply it when it is required. It was the most egregrious act of assumption to have claimed such a title, and there are few engineers who, in the fullest sense, deserve that splendid title of being practical men.

Professor Perry has made that as clear as possible to-day, and the advance in thought that has come of late years has shown that these views are appreciated, and that knowledge, rightly applied, is at the basis of success in engineering.

So also we must appreciate the value he has attached to pure physical science, to laboratory research, and still more to mathematics, which is a tool that enables us to put our knowledge to practical use. I think it was Sir William Siemens who told us that he considered mathematics were a very good servant but a very bad master. Mathematics is really a process of logic, and when your premises are given, your mathematics ought to give the correct deduction and the right conclusion. The difficulty is in getting your premises. Lord Westbury once said, with regard to logical argument, to a rising barrister, "Never be in fault in deriving wrong conclusions from facts: the facts are at your own disposal."

I think we must all have felt, in listening to this address, that there was something that inspired us and filled us with admiration, besides the mere words which were uttered, and that is the obvious thought that had been required, the long period of thought from which this address resulted. We felt that it was evidently the result of years of thinking, and the obvious sincerity and earnestness of the speaker convinced those who might not have held the same views before they came into the room. Again, the charm of language and the telling way in which the facts have been put before us have raised this address very far above the average. In fact, it has confirmed the opinion which, I suppose, is pretty universal among literary men, viz., that the finest, most enthralling, most imaginative and poetic work that has been published in the lifetime of any of us, after the "Prisoner of Zenda," is Professor Perry's book upon spinning-tops.

Dr. SILVANUS P. THOMPSON: This notice will be seconded by our oldest past-President present, who happens also to be the oldest living telegraph engineer, Mr. Spagnoletti.

Mr. C. E. SPAGNOLETTI: It gives me great gratification and pleasure to have the opportunity of seconding the vote of thanks proposed by Professor Forbes. We are all very much indebted for the lesson we have received to-night. I hope all our young members will lay it to their hearts, and

profit by what they have heard, so that they may get their reward. Professor Perry is a man of great energy and power. I believe it is only yesterday he was down at Newcastle, throwing his mantle over the northern branch of our Institution, and assisting in the business there which proved such a very great success. The labours of that day were heavy upon him. He had to be up again early to-day, and after his journey he is here to-night to give us the benefit of his advice. I have great pleasure in seconding the vote of thanks.

The motion was carried by acclamation.

The PRESIDENT: I can only say that it has been exceedingly good of you to listen to me with so much attention. I knew that you would, whatever I might say and whether you approved or disapproved, but I did not expect so much enthusiasm. It was especially good in Professor Forbes to speak as he has done, and it has been very pleasant to listen to Mr. Spagnoletti. Of course I know perfectly well that when you have time to reflect you will like to argue out this whole business, for there is plenty to be said on the other side of each of the questions I have raised. But then we are always saying those other things, whereas to-night I wanted to say *these* things.

When Colonel Crompton and I bicycle together in the morning before breakfast, we take opposite sides and sometimes we change sides in discussing these questions, and I have discussed them with many others of our prominent members, and all through this address I have let you see how well I know that there is another side.

Mr. Spagnoletti has referred to the Newcastle local section. Gentlemen, I have great pleasure in going to see these colonies of ours, and the Newcastle one is as interesting as any. We sat down to dinner last night, about sixty of us; Mr. Heaviside, who has come all the way to hear this address to-night, was in the chair; and a better looking set of heads, engineering heads, thoughtful heads, it would be very difficult to find anywhere. I congratulate you on your colony at Newcastle, and I congratulate myself on not being quite too tired with my two days' journey to read my address to you. I thank you again for your attention and applause.

The Three Hundred and Fifty-first Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, 25, Great George Street, Westminster, on Thursday evening, November 22nd, 1900 —Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on November 8th, 1900, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that they should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Members—

Francis Gibson Baily.

From the class of Associates to that of Associate Members—

Ernest Denn Long.

Messrs. R. Tervet and E. Brothers were appointed scrutineers of the ballot for the election of new members.

Donations to the Library and the Building Fund were announced as having been received since the last meeting, to the Library from Mr. E. Garcke and to the Building Fund from Professor Epstein, Mr. T. Cushing, Mr. W. von Siemens, Captain E. W. Creak, Mr. R. von Boschan, Mr. R. Portelli, Mr. W. M. Mordey, Sir Henry Mance, and Colonel R. E. Crompton, to whom the thanks of the meeting were duly accorded.

The following paper was then read :—

TELEGRAPHS AND TELEPHONES AT THE PARIS EXHIBITION.

By J. GAVEY, M.Inst.C.E., M.I.E.E.

The successive Universal Exhibitions that have been held in Paris since the year 1878 may not inappropriately be regarded as milestones along the road of progress in Telegraphic and Telephonic industries, for each in its time has not only afforded unrivalled opportunities for the study of new work, but collectively they offer conclusive evidence of the value of the various discoveries or fresh departures that have been made from time to time in various fields of research, and the degree of success that has been achieved by past inventors and workers may usefully be laid to heart by those engaged in similar efforts at the present moment. Thus, for example, glancing back at the reports of the Paris Exhibition of 1878, there will be found in the list of telegraphic exhibits the Hughes type-printing, the Baudot Multiple, the Duplex, the Quadruplex, the Wheatstone, and other systems which have achieved permanent success, as is forcibly illustrated by the State Telegraphic Exhibits of working apparatus in the 1900 Exhibition, in which they all appear as instruments in daily use. On the other hand, many apparently promising inventions which were prominent in the 1878 and in successive Exhibitions have either dropped out of sight altogether or are still in the course of development—so far, at all events, as actual practical use is concerned.

Class 26 in the catalogue includes Telegraphs, Telephones, and Phonographs, and I propose to deal with the sub-divisions in this order. Further, I may add that in the brief review that I have undertaken of the exhibits in this class I propose to dwell only on those which show considerable novelty, or which illustrate the progress made during the last decade, rather than to attempt an exhaustive description of the class as a whole.

Under the head of Telegraphs there are three distinct systems of Telegraphy which deserve special mention, each exhibiting considerable merit from the scientific point of view, although possibly they may be unequal from the

practical standpoint. They are designed either with a view of increasing the amount of traffic which can be carried by a telegraph circuit, or of abolishing the transcription at the receiving instruments necessary with Morse methods; but they are based on very different principles.

Rowland's Multiplex.—The Rowland Telegraphic Company of Baltimore, Maryland, exhibit an apparatus of the multiplex type of working which will admit of eight messages being sent simultaneously, four in each direction. The apparatus was at work in the Exhibition, and we were told that satisfactory results had been obtained over a distance of six hundred miles of actual line in America. This is so far in excess of the mileage over which we have been able to work in this country with Delany's Multiplex, that a brief explanation of the principle of multiplex working generally may fitly precede a description of the new invention.

Multiplex telegraphy is based on the fact that the carrying capacity of an overhead telegraph circuit is far in excess of the speed at which a telegraphist can manipulate his key. For example, a wire which, worked by automatic Wheatstone, could dispose of three hundred words per minute, if worked by hand can only carry on an average thirty words per minute. The inventors of the Delany system of Morse multiplex have therefore designed a method of increasing the carrying capacity of a wire, while retaining the ordinary method of key manipulation, which is based on the following general principles: Two commutators, each divided into a considerable number of separate segments, are fitted at opposite ends of a circuit. Groups of these segments are connected in proper sequence to the number of instruments to be worked simultaneously, while between each group certain segments are reserved for the maintenance of synchronism. The brushes to which the line wire is connected are caused to revolve synchronously by suitable means, and as they sweep over the segments they complete the telegraphic circuit for a very brief interval through three, four, or six corresponding pairs of instruments manned by separate operators—first, No. 1 instrument of one terminal station being connected to No. 1 instrument of the other; next, No. 2 to No. 2, and so on. These successive connections follow one another so rapidly that, although the initial

current necessary to signal a dot or a dash in the Morse system from No. 1 instrument at one end to No. 1 instrument at the other may be interrupted four or five or six times, these interruptions are of such brief duration that they do not affect the continuity of the signal received, any tendency in that direction being counterbalanced by suitable methods. In this manner, with the Post Office Delany system, six messages may be simultaneously in course of transmission over the same wire without the signals interfering with each other, so long as the synchronism of the revolving brushes is maintained. This being premised, if the electric current traversed the line from end to end without retardation, there would be no limit to the distance over which this method of signalling would be available. Unfortunately, however, the current is retarded between the forwarding and receiving stations, this retardation being largely due to the electrostatic capacity of the line, in combination with its resistance, and although in practice suitable arrangements provide for a certain amount of retardation of the line current, still a point is soon reached beyond which satisfactory working of the existing Multiplex system becomes practically impossible, the current say from No. 1 instrument at one end arriving at the other end after the line has left No. 1 instrument and has been connected to No. 2.

A modification of the above system, designed by Mr. Pollock, of the General Post Office, is intended to obviate to some extent this difficulty. By an improvement in the method of synchronising which abolishes hunting, and by dividing the commutators into two concentric series, one for transmitting and the other for receiving, and mounting them so that one series may be revolved relatively to the other by a variable adjustment, it is possible to arrange that the receiving contacts shall lag behind the transmitting ones for exactly the period taken by the current in traversing the line. This method is still under experimental trial, but it is at present only adapted for Morse signalling.

The Rowland apparatus has the following promising characteristics :—

Messages are transmitted from several sets of keyboards of the typewriting character, and any typewriting clerks should, with a little practice, be able to manipulate them.

The messages are received on instruments which print them in ordinary type on a long roll of paper, which is perforated at convenient intervals to facilitate division when the received messages are printed.

The electrical apparatus consists of an alternate current dynamo as the source of power, from which a continuous series of electrical undulations traverse the circuit when no printing signals are being sent.

The synchronism between the receiving apparatus and the alternating currents, on their arrival from the distant office, is provided for by means of a small continuous current motor, to which is rigidly geared a little alternator, both fixed on a shaft in the same axial line as the main driving shaft of the receiver. A circuit in which are two condensers, which are alternately charged and discharged from a battery by the to-and-fro movement of the main relay tongue actuated by the received alternations, is so connected up with the alternating motor on the receiver, that when the received undulations from the line and those due to the local alternator on the receiver are in unison, only a continuous uniform beat is heard in a telephone used as a synchronising detector. The speed of the receiving alternator is varied, by the insertion of resistance in the motor driving it, until this result is arrived at. Once attained, synchronism is maintained automatically by the local alternator acting either as a dynamo or motor, according as the speed of the shaft tends to advance or recede. The main driving shaft on which the printing mechanism is mounted is revolved by a second independent motor, and by suitable adjustments of the resistance in this motor circuit the correct speed is arrived at. This done, then so long as the two shafts run with absolute uniformity a little jockey wheel connected to the first rides on a small insulated point in a disc attached to the second. If the main driving shaft lags, the jockey wheel makes a brief contact which reduces the resistance in the circuit of the driving motor, thereby increasing its speed, whereas if it advances a second contact is made which energises an electro-magnet and establishes a magnetic break by the generation of eddy currents in a copper disc revolving between its poles. The synchronising of the two sets of apparatus, therefore, is a relatively simple matter; and as the receiving apparatus is synchronised

so as to run in unison, not with the distributing discs at the forwarding end, but with the retarded currents which arrive at the receiving end, there is no reason to doubt the possibility of working for much longer distances than is possible with the original Delany system.

Geared on to the shaft of the sending alternator is a distributing commutator with fifty-two segments, and four groups of eleven consecutive segments are connected each to a set of eleven levers actuated by the transmitting keys. The odd segments serve other purposes. A second series of four equal segments are connected each to one of the four sets of keys, and these acting on a special electro-magnet on the keyboards admit of any depressed type key actuating the corresponding levers at the right periods only.

When no type keys are depressed, the alternator sends a continuous series of undulations to line, whilst the depression of a key by actuating two out of the eleven levers on the keyboard causes two half waves, always with a complete undulation between them, to be cut off, and this suppression of current actuates the receiving apparatus.

The receiving relay has two tongues: one, already referred to above, serving to establish and maintain synchronism; the other actuating either the printing relays or those for shifting the paper. Each of the four type receivers has eleven electro-magnets in the local circuit of the second tongue of the line relay, each electro-magnet being connected to a segment of the receiving commutator which corresponds with, and revolves in synchronism with, the main commutator on the transmitting dynamo. When no signals are being sent, the currents from the line relay pass through the local relays in such a direction as to keep the tongues against the spacing side, but the omission of two half-waves causes the tongues of the two corresponding relays to drop over to the marking side, and this acts on the electro-magnets which print the corresponding letters, or which shift the paper, as the case may be.

A revolving cylinder, with a transverse mark on the transmitting keyboards, keeps the typewriter at the far end informed of the position of the receiving roll, and advises her when to advance it vertically and shift it horizontally so as to commence a fresh line.

It is stated that each operator can send at the rate of

thirty words a minute, so that with duplex arrangements a speed of 240 words should be obtained, with the advantage that the messages are detached from the receiving instruments in a condition to be sent out for delivery, without the necessity for transcription that the existing method of multiple Morse working of course involves.

Mercadier's.—Monsieur Ernest Mercadier, of Paris, exhibits his multiple telegraph system, in which it is said that twenty-four messages can be simultaneously transmitted over one circuit, twelve in each direction. It is based on the harmonic system of telegraphy, one form of which was devised by Elisha Gray many years ago. Mercadier's method, however, is not a copy of Gray's, as by the use of telephone receivers and transmitters combined in various ways he has designed an absolutely independent method. Harmonic telegraphy depends on the fact that if a number of vibrating reeds, each differing by a certain defined period, say of a musical note, be so connected that each in the course of its vibrations causes a series of currents to be sent into a line wire, the resulting current so formed consists of a series of irregular but well-defined curves, which are due to the combination of the whole series of vibrations emitted by the different reeds, just as in a musical note the sound curve is not a simple one, but is that due to the fundamental note on which are superimposed the overtones. At first sight it would appear as though it would be impossible to dissect the combined current curves, due to the superimposed currents, into their initial undulations. In practice, however, if each of the receiving reeds or telephones, joined up at the receiving end, be tuned to exactly the same pitch as its corresponding transmitting reed at the far end, the receiving reed will respond to the current of the corresponding transmitting reed and to no other, and even though the whole of the transmitting reeds are worked simultaneously, each being used for sending separate Morse characters, the respective receiving reeds select the Morse characters of the right note and disregard all others.

As transmitters, Mercadier uses electrical vibrating reeds of a well-known character, and as receivers he uses a combination of a telephone and a microphone, the latter sending out a powerful series of undulations into the local

circuit, these undulations being selected by suitably designed telephones, which only respond to the vibrations to which they are tuned.

The method, therefore, is a Morse method pure and simple, in which, so far as the operating is concerned, the telegraphist uses a Morse key for signalling, and the receiving telegraphist uses telephones as sounders. I learnt, whilst in Paris, that the apparatus had, in the course of certain trials, worked satisfactorily between Paris and Bordeaux, but it requires a metallic loop for thoroughly satisfactory working.

Virág and Pollak.—Messrs. Virág and Pollak exhibit their photo-autographic telegraph apparatus, in reference to which so much has appeared in the public press.

The original system, as exhibited in the Hungarian section of the Exhibition, consists of a telephonic receiver, to the centre of the diaphragm of which is attached an arm which conveys the vibrations of the diaphragm to a small mirror. A spot of light falling on the mirror is reflected on to a photographic band, and when the instrument is started any movement of the mirror is photographed on the band. Morse signals are transmitted by an automatic method, and the record is impressed on the photographic band in a series of curves representing the Morse alphabet. It is claimed that an abnormally high speed can be attained, but the system had this disadvantage, in common with ordinary Morse methods, that the whole of the transmitted matter has to be deciphered and written out by the receiving telegraphists.

During the meeting of the Electrical Congress held in the month of August, however, a paper was read describing a most ingenious modification of this system, by means of which the telegram is received not merely in arbitrary Morse signals, but in ordinary written characters.

In the modified system a metallic loop is employed, but it is joined up so as to form two circuits, Fig. 5, one being the ordinary metallic circuit, and the second a bridged and superimposed earth circuit of the type well known in telephony. To each of these separate electrical circuits is connected a telephone with a mounted mirror, which is vibrated by the movement of the diaphragm. These mirrors are so placed in relation to one another that a

spot of light is reflected first on one, then on the other, and lastly on the photographic record. The function of one of the mirrors is to receive impulses representing the vertical component of ordinary written Latin characters, whilst the second mirror receives the horizontal components. The transmitting is arranged by means of a punched slip with

PERFORATIONS.

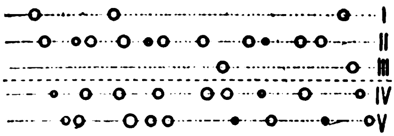

FIG. 1.

VERTICAL.

FIG. 2.

HORIZONTAL.

FIG. .

RESULTANT

FIG. 4.

five series of perforations; the first three transmitting currents to the vertical component mirror, and the second two to the horizontal one. The line of perforations marked 1, Fig. 1, transmits a negative current of a defined voltage; row 2, a positive current of the same voltage; and row 3, a positive current of double the voltage. Rows 4 and 5 transmit through the horizontal component telephone simple reversals.

Two sizes of holes may be perforated along either of the rows, thus admitting of long or short contacts, and by means of a specially designed combination of perforations the vertical and horizontal components are so co-ordinated as to admit of the reproduction of written characters at the receiving end. In the diagram, Fig. 1 illustrates the perforations necessary for the transmission of the word "Telegraph"; Fig. 2 shows the vertical components; Fig. 3 the horizontal; and Fig. 4 the resultant.

TELEPHONES.

The advance in telephonic practice has, on the whole, been greater than in the branch of telegraphs devoted to the transmission of public messages. The invention and perfection of the manufacture of dry-core paper insulated cables has resulted in the more important of the telephonic administrations, both in the Old and New Worlds, undertaking the substitution of metallic in the place of earth circuits for telephonic intercommunication. With the means at their command at an earlier period telephone engineers were practically restricted to overhead work at their large exchanges, and although they realised the disadvantage of earth circuits, few of them could face with equanimity the doubling of the huge number of overhead wires necessary for metallic loops. Now a dry-core cable which will serve two hundred subscribers may be drawn into a 3-in. pipe, and in the course of a few short years an earth circuit telephone will be a thing of the past. Not only has this resulted in a silent and undisturbed subscriber's circuit, but it has admitted of the introduction of improved telephones and improved switching arrangements. With an earth circuit a low-power microphone had necessarily to be used in order to diminish the disturbance on neighbouring wires, for obviously the greater the current emitted, the greater the mutual induction; but with metallic loops improved telephones of the granular type have been generally introduced. The placing of the wires underground has likewise admitted of increasing the number of subscribers connected to each central switch, and this has led to improved methods of automatic signalling.

There is, perhaps, one point in modern telephone work which may here be referred to with advantage, and that is

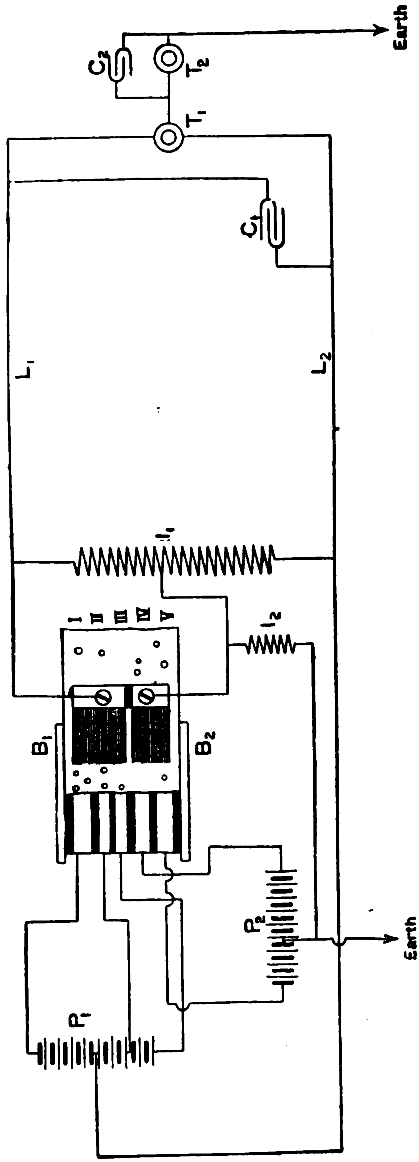

Fig. 5.

the general tendency in the direction of the introduction of automatic signalling in modern exchanges. When first the

Post Office opened its local exchanges in the provinces Sir William Preece insisted on the need for this method in order not only to simplify the work of the subscriber, but to ensure the sending of a ring-off signal to indicate the close of a conversation.

At that date automatic signalling could only be effected by the use of primary batteries at the subscriber's office, and objection was taken to the method on account of the alleged expense of these batteries. Given, however, the necessity for maintaining a couple of speaking cells at each subscriber's instrument, the extra cost involved by the addition of two or three more cells for signalling purposes was not so great as was imagined, for a considerable portion of the total maintenance cost arose from the loss of the men's time in locomotion. The principle has, however, spread, and most modern installations at present comprise some method of automatic calling and clearing signals. The diminution in the work thrown on the operator by the use of a well-designed method of signalling, which reduces the speaking to the mere words, "Number, please," "through," or "busy," is highly advantageous in respect both of economy of working and in facility of manipulation.

Central Battery Telephone Switches.—A central battery automatic signalling exchange switch, exhibited by the Western Electric Company, illustrates the system that is being rapidly extended throughout the whole of the United States, and which has been adopted by the British Post Office in London, by the National Telephone Company in some of its centres, and by the Belgian Administration in Brussels. The system has been described recently by myself and others, and space forbids a complete technical description which would demand a separate paper for due consideration. For the purpose of discussion, however, it may be stated generally that the advantages claimed in favour of the system are broadly of the following character :—

(1) The generation of current in an economical manner at the Central Exchange for speaking and signalling purposes.

(2) Uniformity in the character and volume of articulate speech owing to the speaking current being always necessarily maintained at the point of highest efficiency.

(3) Economy of maintenance owing to the absence of

primary batteries, and the reduction of the parts liable to get out of order at the subscriber's office to the minimum.

(4) A complete system of automatic signalling which reduces the need for the operator's intervention to the lowest degree.

(5) The use of small glow lamp signalling indicators which admits of each indicator being placed in immediate proximity to the jacks or cords to which the indications refer.

(6) The possibility of using coloured lights to indicate special rights, such as toll rates, flat rates, deposit accounts for trunk conversations, &c.

(7) The use of a telephone meter for registering the number of conversations initiated by toll-subscribers. This method is not necessarily confined to central energy switches.

Postel-Vinay Switches.—The French firm of Postel-Vinay exhibited a system recently introduced at the newest of the Paris exchanges near the Avenue Breteuil, the most striking feature of which is a remarkably small and well-designed automatic indicator which can be placed immediately over the jack for working the junction circuits. A set of these is shown on the table, but I think that signalling lamps are on the whole preferable to electro-magnetic indicators.

Siemens and Halske.—The firm of Siemens and Halske likewise exhibit a flat board of considerable capacity with certain details of signalling which are of interest. Time does not admit of a general description, but there is one point of novelty to which reference should be made—that is a combined local subscriber's jack and indicator. The call is indicated by the appearance of a small disc at the mouth of the jack. The disc is attached to the extremity of the armature of a Hughes electro-magnet. It is held in position by the magnetism of the core, is released by the reversing action of the current indicating the call, and is restored to its normal position by the mechanical insertion of the answering peg. It is, of course, again held in position by the permanent magnetism of the retaining electro-magnet.

Again, an ingenious method of automatic ring-off is provided by means of a local battery joined through the indicator at the exchange, the effect of which is neutralised

by an opposing polarisation cell at the subscriber's office, which is in circuit when the speaker's telephone is off the hook. At the close of the conversation, however, and on the restoration of the telephone, this second cell is out of circuit, the local battery in the exchange actuates the indicator, and the connection is severed by the operator.

It may be observed that Messrs. Siemens & Halske in their descriptive pamphlet specify the following conditions for satisfactory exchange working :—

1. The Exchange should possess the greatest possible facilities for accommodating new subscribers, hence :
   (*a*) The jacks must be as small as possible, yet not so small as to impair their insulation and durability.
   (*b*) All other parts must also be very small and compactly built (the indicators are placed out of reach and are self-restoring).

2. To economise expenditure for working, fitting, and space, the manipulation required must be reduced to a minimum, so that one operator may attend to as many subscribers as possible. To achieve this,
   (*a*) The indicators must be self-restoring, and the operator's speaking apparatus must be placed in circuit automatically.
   (*b*) The clearing signal must be perfectly certain in its action, and must not depend on the subscriber.

Party-line Telephones.—Several forms of party-line telephone circuits have been designed and exhibited, *i.e.*, arrangements designed to serve several offices on one circuit. These are used largely on light railways to provide communication between the headquarters and the various stations on a circuit, each being called by a step-by-step arrangement at will, without disturbing the others. The step-by-step switches which are placed at each office are actuated by battery currents of one polarity, and when these switches are in the position indicating the number of the office required, a reverse current is used for ringing up the "Wanted" subscriber. A needle on each of the dials indicates the number of the office that has been called, and by so doing it further announces the fact that the line is engaged.

There were likewise one or two automatic telephone switches which provide for subscribers to a small telephone system obtaining connection with other subscribers without the intervention of a switching operator. So far these systems have a limited use where a service designed to provide for special conditions is required.

A neat little switch-board for private use was shown by the "Société par Actions du Bureau Electrique," in which connection between any two lines is effected by pressing a button which makes the necessary line contacts and remains depressed until on the receipt of the ring-off signal it is released by giving it a quarter revolution on its axis. It then springs back automatically into the position of rest and restores everything to the normal condition. The use of pegs and cords is thereby dispensed with.

Carbons for Microphones.—The manufacture of carbon granules for microphones has received considerable attention. These appear in two forms—one the irregular granule that so far has been most generally used in this country, the other consisting of small spheres varying in size from ordinary dust-shot to the $\frac{1}{16}$th of an inch in diameter. There appears to be little to choose between the two forms of granules for microphone purposes.

I observed great diversity in the details of construction of telephones and microphones exhibited by French firms. The State Administration compels subscribers to provide their own telephones, and these may be purchased at will from any one of a number of manufacturers who comply with the specification of the Administration. The result is that a very large number of local manufacturers have sprung up throughout the country, each exhibiting a special telephone which differs in some local details from all others. The result, from an exchange point of view, is not good. The speech from different subscribers varies materially according to the type of instrument used, and none of these local inventions are better than the ordinary type of telephone in use in this country.

As illustrating various modern methods of laying underground conduits for telephone and power circuits, the cement duct system designed by Mr. Hultman, of Stockholm, was exhibited in the Swedish section, and the Belgian Administration showed in their State Pavilion a section of

the single-duct built-up system which they have laid in Brussels. Both these methods are in use in this country, the Hultman system having been very largely used by the National Telephone Company, whilst the single-duct built-up method has been adopted by the Post Office for its London telephone system. The Hultman system is perhaps the cheaper of the two, whilst on the other hand the built-up system is, I consider, the stronger and more reliable. A few blue-prints illustrating the method of construction used in London are on the table, and can be examined at the close of the paper.

WIRELESS TELEGRAPHY.

There are four exhibits of wireless telegraphy in the exhibition.

Post Office System.—An illustration by means of coils of the Post Office Electro-magnetic method originated by Sir William Preece appears in the Post Office exhibit.

Ducretet and Popoff.—Monsieur Ducretet exhibits his Hertzian system, which it is understood he designed in conjunction with Monsieur Popoff, the Russian inventor, and which has been adopted in the French Navy and, it is believed, in the Dutch. There was nothing to specially distinguish it from the Marconi system in this country.

Slaby and D'Arco.—The Algemeine Elektricitäts Gesellschaft exhibits a system designed by Slaby and D'Arco in Berlin, and this deserves a little consideration, as the inventors have replaced the usual vertical insulated wire, so well known in connection with wireless systems in this country by a vertical cage, the upper end of which is connected to earth. This is illustrated in Fig. 6. At first sight it would appear as if the effect of the cage would to some extent be neutralised by the waves emanating from the return wire to earth, but probably the self-induction of the earth wire practically confines the oscillations to the cage. This, however, is an interesting subject for speculation and investigation.

The American Wireless Telegraph Company exhibits a system in which a pneumatic arrangement has been designed for decohering, the object being to reduce the number of relays and magnets in the combination, with a consequent

diminution of the local Hertzian waves which tend to interfere with accurate reception.

Poulsen Microphonograph.—Perhaps the invention of the greatest scientific interest is the Poulsen Microphonograph, by which a telephone conversation can be permanently recorded on a steel wire, and reproduced at any time.

In this apparatus a steel wire, or a steel band, is moved by any suitable means with considerable velocity between the poles of a small electro-magnet. On speaking into a telephone transmitter joined on the circuit, the undulatory

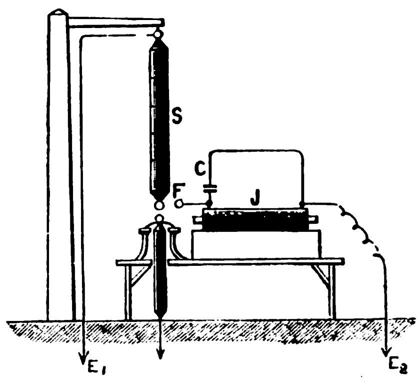

FIG. 6.

currents set up in the transmitter react upon the electro-magnet and cause a continuous variation in the direction and in the degree of magnetism at the poles of the electro-magnet. These variations are permanently recorded on the steel wire as it rushes by, and when the message is complete the steel wire retains a definite record of what has taken place in the shape of a continuous series of transverse magnetised lines varying throughout in their polarity and in their strength. On connecting a telephone receiver to the electro-magnet, and again starting the wire on its course, this magnetised wire generates electric currents in the coils of the superimposed magnet as it passes between its poles, and these electric currents, which are the exact counterpart of those generated by the original voice, cause the telephone to repeat what was said in an almost absolutely perfect manner. In one variation of the instrument an endless

steel band was caused to revolve at a high speed around two wheels which stretched it out to its full extent. On one portion of the band was placed a magnet connected with a microphone; further on were half a dozen electro-magnets connected with as many telephones; and finally an electro-magnet through which circulated a permanent current. As the band rushed by in the course of its revolutions it picked up the magnetism from the speaking microphone circuit, next it reacted on the electro-magnets connected to the telephones and caused them to speak, and, finally, on passing under the electro-magnet through which a steady current was flowing, the whole of the impressed magnetism was neutralised and the band wiped clean, so to speak, and rendered ready to receive a fresh impression.

At present this invention is in the early stage of scientific discovery. It may be used by a telephone subscriber to record an important communication, and it promises to afford means of obtaining a telephone repeater, a problem which has been before the electrical world for the last twelve years, and which so far has not been solved in a satisfactory manner. A telephone repeater would increase the range of telephonic speech and decrease the cost of long lines. The President of one of the American telephone companies some time ago offered publicly a reward of 1,000,000 dollars for a thoroughly satisfactory telephone repeater, but the money has not yet been earned.

Telephone Hirmondo.—Amongst the miscellaneous exhibits is one by the "Telephone Hirmondo" which provides news and musical transmission alone, but without telephone intercommunication, in the city of Buda Pesth. Technically there is very little information to be derived from the exhibit, which is rather statistical than technical, but I was rather surprised to learn that the number of subscribers to the system had increased from 3,750 on the 1st of January, 1895, to 7,560 on the 1st of January, 1900, all the wires being overhead. In practice items of news are spoken into the main transmitting telephones at the central station every quarter of an hour, and such items are repeated until a fresh batch is started. So far it is an electrical substitute for an evening paper combined with a theatrophone installation.

I came across a novelty in telephone administration. In

the capital of Mexico they have absolutely free trade in telephone exchanges, which may be erected by any body or company with the sole proviso that there must be inter-communication between the systems. There are eight separate companies at work, with an aggregate of 4,000 subscribers, the average rate of payment being 12½ francs per subscriber per month.

At the meeting of the Electrical Congress various papers were read which have been or will be published. A committee was likewise formed to consider the question of units, and some radical proposals were brought forward, which would have involved an entire change in the existing methods of electrical measurement. The whole subject was very keenly debated, and anything in the nature of a radical alteration was outvoted. The committee restricted itself to giving definite names to two of the existing units, which up to the present had been known as the "C.G.S. unit of magnetic field," and the "C.G.S. unit of magnetic flux." These propositions were then submitted to a meeting of the Official Delegates, and were practically carried unanimously. A further proposition was submitted to the delegates to the effect that electrical energy was property, and that its theft should be punishable by law. This was also carried. In Great Britain existing Acts of Parliament define electrical energy and provide against its theft, but in certain countries it has been argued that electricity cannot be weighed, and that no punishment can be inflicted for stealing it, hence the above resolution.

In the foregoing curtailed review it is of course impossible even to refer to many of the excellent exhibits of working apparatus, line stores, cables, both submarine and subterranean, and other modern and up-to-date telegraphic and telephonic materials and appliances that were to be seen at the Exhibition. If I have had occasion to omit even a casual reference to many beautiful and elaborate exhibits, this is not due to want of appreciation, but to the fact that to do justice to all would involve a complete treatise on telegraphs and telephones. It is hoped that the few remarks I have made on the most striking developments will be of sufficient interest to have justified the presentation of this paper.

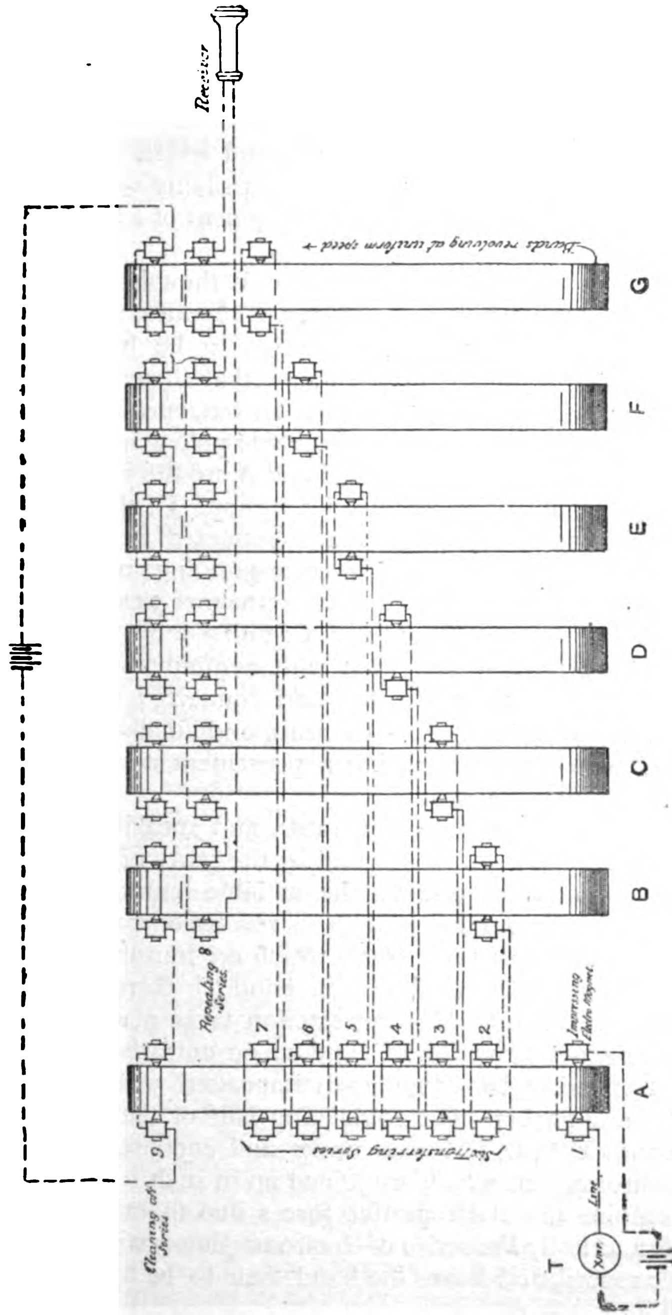

FIG. 7. (See Addendum, p. 92.)

ADDENDUM.

The author in the course of his paper sketched on the blackboard the figure given on p. 91, and added the following explanation with regard to the possibility of applying the Poulsen microphone to the development of a telephonic repeater :—

As illustrating a method which it is thought might be developed into a satisfactory telephone repeater, the following was suggested as a groundwork to be built upon. Assuming, as illustrated in the figure, that there are six or more endless steel bands, A, B, C, D, &c., revolving at an absolutely uniform rate around suitable pulley wheels, and that, approaching closely to the band A are the poles of an electromagnet 1 connected to a telephone T; that a little further on an electromagnet 2 is mounted in a similar manner, but connected to a corresponding magnet on band B, and beyond this an electromagnet 3 establishes a relation between bands A and C, and so on, next that bands B, C, D, E, F are fitted with a number of electromagnets, 8, joined up in series and connected to the line over which it is desired to transmit, and finally a series of electromagnets through which a permanent current circulates are fixed at point 9.

Then, on starting the apparatus, and speaking into the telephone T, band A is energised by the series of transverse magnetic polarities due to the variable currents in the electromagnet. As the band in its revolution passes under magnet 2 it generates currents which are transmitted to its corresponding electromagnet on band B, there to repeat the magnetic effect. The same action takes place between electromagnet 3 and band C, and so on until the whole of the independent bands are each impressed with the same magnetic alphabet. On completing half of the revolution the bands B, C, D, E, F pass under and energise the series of electromagnets which are joined up in such a manner as to combine the electromotive forces due to each separate band, and lastly the series of electromagnets 9 wipes out the whole record, and leaves the bands free to be acted on by fresh impressions.

Sir WILLIAM PREECE: It does my heart good to see such a crowded assembly to listen to an address which has telegraphy principally for its text. And looking round this room, I cannot help going back to the early stages of the history of this Institution, when sensation after sensation was brought before us, and the room itself was filled to overflowing, and applause as ringing and as cheerful as that which you gave Mr. Gavey at the cessation of his paper was the order of the day. I wonder if young members of this Institution ever take the trouble to read the early volumes of the Proceedings. They will find there a good deal that is interesting; they will find there a good deal to learn, and a great many facts which would save them from many troubles. It is not the first time that we have heard a paper in this room describing the exhibits as shown at different Exhibitions. I have had the gratification myself on more than one occasion of bringing before the Institution things shown in Paris, in Chicago, in Philadelphia, in Münich, and in Vienna, and I hope and trust that the practice originated in the very early days of the Institution will be continued, and that we shall take every possible opportunity to find out what progress is being made in other countries, and to show that we are not behind. If we do not look out, however, we shall get behind. Sir Wm. Preece.

It is a remarkable fact that, in nearly all branches of progress the growth of business varies almost exactly with the growth of the capacity for carrying that business. Mr. Gavey has brought before us several novelties shown in Paris—Rowland's Multiplex, Mercadier's Multiplex, Virag and Pollak's system, and other improvements; but this axiom, or maxim if you like to call it so, that the growth of business varies with the capacity for conducting that business, is not confined to telegraphy: it is true of telephony, it is true of electric traction and electric railways: it is true for every branch of the applications of electrical industries. We never have had it more strikingly shown than in the fact that in England and in America, and wherever telegraphy has progressed, while the rate of increase of length of wire grows in a straight line, or in arithmetical ratio, the rate at which the business increases is a rapid ascendant curve; and it shows that, while we are able to compete with that business and perform the work as fast as ever it was done before, and sometimes faster, the invention of the electrical engineer is exceeding the rate of the growth of the erection of the wires, so that, at the present day, a circuit will carry quite ten times as much as it carried when this Institution first commenced its meetings in this room. That is a great fact, and Mr. Gavey has well brought it before us. He has told us a great deal about telephones. Well, that is a large subject. The telephone was first shown in this country, I believe, in Plymouth, and next in this room, and a crowded meeting assembled here to see this wonderful instrument for the first time. Twenty-three years have elapsed since that period, and where are we now? Is the telephone industry in this country in a flourishing or in a proper position? We see a kind of triangular duel going on. We have on the one hand a company striving hard, doing its best to maintain a very difficult position; we have municipalities springing up trying to emulate their would-be competitor; and we have in the background a small depart-

Sir Wm. Preece.

ment called the Post Office Department, that does its very utmost to meet the wants of the public, and has this great advantage over every other one of its competitors, that its back is broad enough to bear the greatest possible abuse which can be brought against it. I envy the position of Mexico. There, Mr. Gavey says, everybody may start his own exchange, and be placed in communication where he likes and with whom he pleases, on condition that they are to have free inter-communication. But how are they to have free inter-communication? for every inventor has his own switch, his own transmitter, and his own instrument? The difficulty is bad enough as it is, with three competitors. Mr. Gavey, I think, said there were six in Mexico, and probably that will grow in the same compound ratio. And when those who have been to Mexico next go there, perhaps the six may become sixty times six, and then where are you? If there is a business in this world that should be manipulated and managed by one administration, and by one concern, that should be conducted exactly on one principle, it is the business of telephony. I did hope that I should see a day when every house in this country should have its telephone, and that there would be a practical and easy mode of placing every house in communication with every other house in the whole of the United Kingdom. That is thrown to the winds with a great many other wild illusions and wild imaginations. It may come in the distant future, but I am afraid that, with grey hairs coming so rapidly, I shall never see my ideal telephone system carried out.

Mr. Gavey told us something about the exhibits of wireless telegraphy. We are getting tired of wireless telegraphy. The papers are still continuing to take it up wildly, and to advertise strange experiments in different places, but we want to see practical wireless telegraphy—and where do you find it? Is there at the present moment anywhere a single circuit worked commercially on a practical system of wireless telegraphy? If there is, let somebody come and read a paper before this Institution. The only place is the Post Office. The most beautiful thing, the greatest novelty that Mr. Gavey has brought before us, is this Microphonograph of Mr. Poulsen's. Apparently there is very great difficulty in showing it in operation. I could not see it in Paris; I tried very hard, but I could not see it there; it had been sent to Berlin. But it is coming, and it is a very marvellous thing. It is not only in itself, as the description has shown us, beautifully designed, based on beautiful principles, but it is one of those things that is going to open the eyes of all our physicists, scientists. and theoretical men, on the question of the molecular character of magnetic and electric operations. There is nothing, to my mind, so marvellous as the continual exchange through electrical actions and magnetical actions, through steel, and through circuits of these curious changes of position, form, motion and shape that we sometimes call electrical and sometimes magnetical, but are all brought out in this beautiful instrument of Mr. Poulsen's.

Lastly, Mr. Gavey referred to the work done by the Congress. He mentioned the fact that the Congress had decided upon introducing or recommending the adoption of two units, (1) the "C.G.S. unit of Mag-.

Sir Wm. Preece.

netic Field," and the other "C.G.S. Unit of Magnetic Flux." But he did not mention that the name accorded by the Congress to the unit field was the name of Gauss, and that that accorded to the unit flux was that of Maxwell. I have serious doubts whether the name Maxwell will come into practical use. Probably the abbreviation into the word "Max" may come into use, but I have little doubt that those who lead and who are our writers may probably take up the unit of field and call it the Gauss, and that that will rapidly come into general use. Gentlemen, I am proud to see my successor in the technical chair at the Post Office bring a subject before you with the clearness that Mr. Gavey has to-night, and I hope and trust it is only one of an annual display on his part of the progress made in a branch of electrical industry that is thought of too little; and I am sure that the old telegraphic faces that I see here to-night will be tempted perhaps to come again and see for themselves, or hear for themselves, that other branches of electricity are as interesting to them as telegraphy and telephony.

The President.

The PRESIDENT: Of all our visitors from America, I believe Mr. Hammer alone remains. We should be very pleased to hear any remarks from him.

Mr. Hammer.

Mr. W. J. HAMMER: I have had the pleasure, since I visited the Electrical Congress at Paris, of taking a trip around the Continent, and I have seen a great many very interesting things, both electrical and mechanical. But I am scarcely prepared to stand before an audience of this character and speak without some preparation or in a superficial way of many of the things which I have seen. One of them has been referred to here to-night, but I think it has been given a wrong title. The Telephonograph, I believe, is the correct title of the instrument. I have recently been in touch with some of the people who are identified with that instrument, and they have expressed themselves strongly as desiring to have that name used. I saw in Berlin some very interesting modifications of that instrument, and some very interesting experiments, but I hesitate about speaking on them because they were shown to me under rather peculiar circumstances, and in view of certain patents I do not think it would be well to refer to them here: but I can heartily endorse what Sir William Preece and Mr. Gavey have said about the remarkable interest which this instrument has aroused at the Paris Exhibition, and of its beautiful simplicity and perfection. I have had considerable experience in connection with phonographs, and working with them, and have tried most of the different modifications of phonographs that have been made, and I certainly never have heard anything in the way of a speaking machine that will touch the telephonograph. With every instrument in which the sound-waves are recorded by something in the way of a stylus, there is bound to be a noise which cannot be eliminated, but where these lines of force are stored up in the wire in the silent manner in which they are, the most perfect reproduction is produced. In Paris and also in Berlin I made some experiments in using words, the recording and reproduction of which is very difficult in a phonograph, also in breathing and whispering and that kind of thing, but all of these are perfectly reproduced by the telephonograph. So that

Mr. Hammer

I feel very certain in my own mind that it is superior to anything that has ever been made in the way of a talking machine.

I had the pleasure of seeing a little of the Nernst lamp whilst I was in Paris, and in following it up somewhat on the Continent, but that is a subject that does not really come within the province of the discussion of this admirable paper that Mr. Gavey has brought before you; in fact, quite a number of the subjects that I have looked into and studied during my sojourn in Europe, have no direct bearing on the paper, so I hesitate to mention them. But there is one thing which Mr. Gavey brought before you that I had the pleasure of seeing in Buda Pesth, and that is the Virag and Pollak system of telegraphy. I have some samples of the writing, and I have seen the apparatus in operation. It is certainly in its present form a most interesting and promising invention, and seems to work in a most satisfactory manner.

Mr. Roberts.

Mr. M. F. ROBERTS: Mr. Gavey has told us of the difficulty he has had in explaining the operation of one of the instruments owing to the request that was made to him not to reproduce the diagrams. A similar wish on the part of many of the exhibitors was one of the great difficulties I met with in studying the different exhibits in the class of Telegraphs and Telephones in the Paris Exhibition. I found that, with one or two notable exceptions, assistants were in charge of the exhibits who either had not the necessary knowledge to explain them, or who were definitely instructed not to do so. The difficulty was added to by the want of a suitable catalogue. I have been told by different gentlemen who sent workmen specially over to the Exhibition, that the visits in many cases were of little use, simply because the representatives they sent could not obtain the information they wished them to get. In the case of telephones and telegraphs, I think we may say generally that, with one or two exceptions, perhaps, which Mr. Gavey has pointedly brought before us, the improvements are to be found in points of detail. I should have been particularly interested if Mr. Gavey had extended his remarks with reference to the progress made between different Exhibitions by briefly referring to what had been the most marked improvements since the Exhibition of 1878. To my mind it appeared that, in the case of telegraphs, the improvements very largely consisted of higher finish in the apparatus exhibited, whereas in telephony the improvements appeared to be chiefly in the simplification of parts and the design of parts which can be readily produced at cheap rates. Of course we can understand the development in the case of telephony taking this line, because there is such an enormous multiplication and reproduction of the same part, whereas in telegraphy the problem that has to be dealt with varies considerably in almost every case. Not only, too, does it vary in the case of a given line but it may perhaps vary markedly at different times of the day. The successful design of parts for telephone-working appears to be largely due to the specialising of certain forms. For example, in the case of one of the exhibitors to whom Mr. Gavey has referred, I found that the firm had one gentleman present who had made a special study of switch-boards, another who had made a special study of telephone instruments, and a third who told me his department was to give in-

formation respecting dynamos. We can easily understand, when a powerful firm has representatives and employés who devote their attention almost exclusively to one part, that we get these improvements which Mr. Gavey called attention to in the case of the central battery system of working, and it is this specialising in America which has resulted in the very great progress which was noticeable in the American exhibits in the Paris Exhibition. Mr. Gavey has also called our attention to the Rowland's telegraph apparatus. If we go back to former Paris Exhibitions, in every case I think we have had type-writing instruments, but it is an astonishing fact that type-writing machines have made such little headway in this country. Nothing is more to be desired than a type-written message, but yet at the present time such a message is practically unknown in this country. I do hope that the very successful exhibit of the Rowland's Company will have the effect of popularising the use of the type-writing telegraph here. Mr. Roberts.

Mr. A. W. HEAVISIDE [*communicated*]: Whilst thanking Mr. Gavey for his brief review in popular language of the Exhibits, Class 26, of the Paris Exhibition of 1900, one is tempted to ask for more, the motive being that subjects so deeply interesting as electrical application in any form, need much detail to be of practical utility. Mr. Heaviside.

So far as I know, though much experience has been gained in the use of the Delaney multiplex system, the valuable electrical data relating thereto has not been published to the world. For instance, how useful it would be, if the profession were fully acquainted with actual time-lag under practical conditions with given conductors, both copper and iron, with an impressed force of a given value, the effect of leakage at the insulators, the practical difficulties experienced in a variable climate like ours, with rapid alterations of heat and humidity, frost, snow, and sleet and rain in twenty-four hours.

Similarly, in Rowland's multiplex, one is tempted to ask, does abrupt omission of two half waves produce any deleterious re-action from the electro-static discharge. The operator's control of the position of the receiving roll by means of a transverse mark appears to be weak. This roll, if feasible, should be automatically controlled. The advantage that the messages are delivered from the receiving instrument in a condition to be sent out for delivery, is no mean one, if it really saves a corresponding number of receiving operators.

Mercadier's system of super-imposed vibrations at the sending end, and selective apparatus at the receiving end, is most suggestive. If twenty-four super-imposed vibrations can be sent simultaneously, and each receiving apparatus can be tuned to respond only to that which belongs to it, then why not have a main pair of conductors of considerable cross-section with twenty-four loops of variable length to twenty-four different stations ?—what a saving of wire and unburdening of the telegraph lines, which groan under their ever increasing load, this would lead to. Of course, metallic loops must be used, and this speculation revives a 19-year-old suggestion of mine for working the Wheatstone automatic and is probably worth trial, as anything that has for its object a reduction in the number of wires and stability of signalling is worthy of much thought.

Mr. Heaviside.

The tendency of the age is to work all electrical currents in metallic loops, which surely will become increasingly necessary as electric light and power applications are developed. Our mother earth is impartial, she treats all her children alike, her ample bosom receives them all, they lose individuality, which is the very essence of the telephone and will become a necessity with most other apparatus—though all the work of transmission and signalling is done in the environment, after all, the guides, in our present state of knowledge, in spite of Marconi's practical application of the labours of Righi, Branly, Lodge, and others, cannot be dispensed with. Virag and Pollak's photo-autographic telegraph apparatus is marvellously clever, but apparently wanting in simplicity at present. That it may become commercially applicable every one desires, and to throw cold water upon it would be as bad as calling the telephone a philosophical toy!

But, may I venture to suggest in this, and in all other systems described by Mr. Gavey, how useful it would be at least to append to his paper a theoretical diagram illustrating the principle of each case. It must be remembered that there are many students of the Institution, and life is too short for every individual member to look up all the authorities. It is a case of "Science Abstracts" over again. One at least wants to know the text, and one can draw the moral in solitary railway journeys and other fugitive snatches of time for thought that offer in these busy executive days.

Central battery telephone switches are on their trial, and if the extensions from the simple subscriber's circuit from his telephone to the central exchange can be adapted to the many diverse needs the telephone has to meet, it will probably have come to stay. It is hoped that the new decade will see such a development of the telephone in Great Britain and Ireland as shall remove the reproach that we now suffer from of being behindhand as compared with other countries. One feature of the central battery system, if I rightly understand it, is that it secures privacy of communication between the users, a feature that has distinguished the Newcastle-upon-Tyne exchange for many years and commends itself to all.

Then as to carbons for microphones, much is still wanting in microphones; how to get loud speaking without jarring, has been a problem since the days of Hughes, and it still remains a problem. An ideal microphone should respond in indentically the same manner from day to day to every vibration with great delicacy, and invariably recover itself without lag or jar. Take a curl of horsehair as used in domestic furniture. In general, it yields and recovers from any impressed force with precision, its elasticity being so great and its fatigue so small; and if carbon filaments could only be manufactured with similar qualities and arranged in companionship like the horsehair composed of many filaments, an ideal microphone might result. I have experimented with carbon filaments and have found the most beautiful speech result, but their brittleness brought with it a short life. Perhaps makers of incandescent lamp carbons could solve the problem. Would that we knew of all the failures and could thus avoid much trodden ground!

Of Poulsen's microphonograph one can only admire and wonder, what next?

Mr. Dane Sinclair.

Mr. DANE SINCLAIR: I do not know that there is much to be said on Mr. Gavey's excellent and clear paper. He has described to us what he saw at the Exhibition. The improvements in telegraphy, when summed up together, are in themselves as beautiful as they are marvellous. The improvements in other directions, and especially in telephony, he has referred to graphically, and, I think, accurately. I am not sure whether he may not be too enthusiastic on the common battery or central energy system; it is just possible, but time will show. When Mr. Gavey spoke of the latest invention in telephony connected with the phonograph he called it the microphonograph, but another gentleman who has spoken prefers to call it the telephonograph. I think the latter is perhaps the more accurate description, but in justice to Mr. Gavey I may say that when I was at the Exhibition the name which he has given to it was the name by which it was generally known. In connection with this I am glad to say that for once in my life I have been ahead of my good friend, Sir William Preece. When I was at the Exhibition I had this thing placed before me and set to work under all the conditions that I could possibly wish for. To me it seemed marvellously pretty and wonderful. There is no doubt, as Mr. Gavey and another speaker have already said, that it gives us a distinct record of speech, so distinct that it cannot be compared with any record we have had hitherto. A long steel wire is wound helically on a drum, the revolution of the drum causing the wire to pass in front of and against the attenuated poles of a receiver magnet. By this means the variations of magnetism caused by the currents from a transmitter in the circuit are magnetically recorded on the steel wire, so that when the latter is again driven past the receiver poles the original speech is reproduced in an ordinary telephone receiver absolutely pure and without any of the grating sounds that come from the phonograph. If this invention does give, as Mr. Gavey hints it may, a telephonic relay, then it passes at once out of the range of purely scientific interest into that of commercial value. Under Sir William Preece's directions very heavy copper wires have been erected from one end of this island to the other. If we can have a telephonic relay, these heavy copper wires of 800 lbs. to the mile become no longer a necessity. They are good in themselves, but if science can teach us how to make a telephonic relay possible, large copper conductors will become things of the past. Of course the advantage to users will be that as the price of the conductors goes down, they will in time get the benefit of that reduction. I was very much impressed by this invention, and believe with Mr. Gavey that there are large possibilities in its future, and I was rather disappointed to see that it was not spoken of by the electrical press in London in a way that I think it deserved.

Mr. Kingsbury

Mr. J. E. KINGSBURY: With regard to that instrument, which does not seem yet to have been effectively christened, I confess when I saw it I thought that whilst we gave credit to Professor Bell for a very bold idea in expecting to put on to an electrical wire electrical undulations representing sound-waves, I thought that to go just this step further and magnetically record those undulations on a wire was an idea hardly less bold. As a scientific instrument, as Mr. Gavey says, it is of the

Mr. Kingsbury.

greatest interest. Of the exhibits at Paris we are bound to give it the first place, and to regard it as a grand application of a very clever idea. The practical uses which may lie in store for the instrument it is, of course, a little too soon for us to remark upon. I would like to say one word in reference to Mr. Gavey's observations on the application which the Post Office have made of automatic signalling. The Post Office introduced in the first instance a telephone system which enabled a signal to be sent automatically, requiring no exertion on the part of the subscriber, sending a signal by the natural operation of taking the telephone off the hook. The Post Office adhered to that system absolutely, much to the surprise of some people who thought, perhaps, it had not all the good features that it should have. It had, at least, that important feature of automatic signalling, to which attention is necessarily drawn now, and which forms one of the features of the central battery system referred to by Mr. Gavey. That system is not only an application of one important feature such as automatic signalling, but such features as the centralisation of the battery and the energy required to work the system. Nor is it a system which has been developed in a day. Twenty years ago a patent for the centralisation of transmitter batteries was taken out by Mr. Scribner, to whom, perhaps, the largest credit is due for the later developments. Mr. Heaviside, in his communication, thinks that the system may live when it is adapted to all the circumstances of the telephone service. I think it may be said that there are no conditions of the telephone service known to practical telephonists which the central battery system, described and shown at the Paris Exhibition, does not meet. Mr. Sinclair is of opinion that Mr. Gavey is a little too sanguine. I think Mr. Sinclair ought to have expressed those views a little more strongly, and given some reasons for them. My impression is that, as a member of the Jury of the Paris Exhibition and in some other capacities, Mr. Gavey has made a sufficiently thorough study of that system to express an opinion. It may be that Mr. Sinclair will agree later on, when time has still more shown the satisfactory working of the system.

One point with regard to the telephonic repeater. I would remind Mr. Gavey that, whilst, perhaps, the question may have been raised more specifically twelve years ago, still it is of earlier origin, for Gilliland took out a patent for a telephonic repeater in 1879. About that time there was, so to speak, an epidemic of telephone repeaters, although there was no million-dollar-reward for them. It is a curious thing that when there is no large reward offered there seems to be a prolific supply, and now there is a large reward I do not know of anything in the nature of a practical repeater put forward. The first telephonic repeater does, to my mind, seem to have the germ of a working instrument, even more so than the beautiful instrument we have had described here. The idea was to have a telephonic diaphragm as a receiving instrument, and make it a combination instrument, attaching it to a microphone transmitter. Although the original instrument has been before the public for twenty years, it has not been developed to any practical stage.

Prof. Thompson.

Professor SILVANUS THOMPSON : Three points in Mr. Gavey's most interesting paper seem worthy of additional remark. The new magnetic units with which the Paris Congress has endowed us are certainly a great boon in, at any rate, speaking about magnetic quantities. We are able now to say definitely that when the earth's magnetic field is to be described as having a strength of 0·18, it is not 0·18 hung up in the air with nothing to it; it is 0·18 *gauss*. We have all sorts of magnetic fields which can be easily described as to their intensity, up to the strong magnetic field in the air-gap between the poles and the armature of a dynamo, which may run up to be as strong as 6,000 or 7,000 *gausses*. It is a great gain to have a word to tack on to the idea. I am not quite so sure that the other name, *maxwell*, is destined to receive the same immediate use as the word *gauss*, because it is merely a synonym for that for which we had a shorter name before, viz., a magnetic *line*, and it is just as easy to talk about one million lines as one million maxwells; indeed, it is rather shorter to say a "megaline" than a "mega-maxwell." I wish they had given the name maxwell to the product 10^8 magnetic lines, so that we could have had the one *maxwell* as the name for that amount of magnetic flux which if "cut" in one second would produce an induction of one volt.

I had an opportunity of inspecting the method of wireless telegraphy devised by Professors Slaby and Count Arco, not only in the Paris Exhibition, but also, previously, in Berlin, and to witness its working from Berlin to Oberschönweide—I do not know how many miles; some seven or eight miles, at any rate. I do not think that the diagram in the paper, however excellent it may be, would quite convey to anybody who had not seen Arco's arrangement exactly what it was. The vertical cylinder in Fig. 6 represents the wire cage—if you can call it a cage—made of either six or eight wires, I forget which, quite ordinary thin wires about 100 or 150 feet long, joined to a ring about six feet across at the top and another ring six feet across at the bottom, and slung from a tall chimney, or something of that kind. It is very remarkable indeed that you should be able to send wireless messages from one of these cages to the other when the tops of the cages as well as their bottoms are earthed. The one thing on which emphasis has hitherto been laid in wireless telegraphy, so-called, was that you should have an elevated and insulated conductor. Well, this conductor may be elevated, but it is certainly not insulated, and nevertheless signals are transmitted with absolute certainty.

Lastly, I also would like to bear testimony to the extraordinary perfection of articulation, of that recording and speaking phonograph and telephone which I had the opportunity of seeing in Paris. It was not then called either the microphonograph, the microtelephone, or even the telephonograph; it was called the *telegraphon*.

Mr. Gavey.

Mr. J. GAVEY [*in reply*]: My reply on the discussion need not be lengthy. Mr. Roberts referred to the desirability of pointing out more definitely the improvements which have taken place in telegraphy and telephony between the year 1878 and the present date. Now, in preparing this paper, I inclined to make it suggestive rather than to

Mr Gavey. state too definitely what I thought the improvements were. But in answer to the remark I should like to say this, that although between the year 1878 and the present time improvements in telegraphy, except in details, have not been marked, I certainly think that combining what we have seen at the Paris Exhibition with other inventions which did not appear amongst the exhibits, but which are coming to the front, we may expect very marked improvements in our methods of telegraphy in the immediate future. What I mean is this. At the present time we have in England and America our good old servant the Morse system, which has rendered invaluable service throughout the whole of the world, but which I cannot help thinking is not quite up to our modern requirements. I am looking forward to an improvement in the direction of transmitting messages by a simple method, such as a type-writing key, which will either transmit direct, as in the Rowland's, or which will perforate slips, as in methods designed by a couple of other inventors, slips that will be passed through an automatic transmitter at a high speed, and that will admit either of the typing or of the writing out in cursive characters the messages at the far end without the necessity for transcribing, and without, let me say, the somewhat messy operation of sticking down Hughes' slips on a sheet of paper. In making that remark, I wish it to be understood that I do not in the slightest degree wish to undervalue the lovely instrument that was designed by Professor Hughes, and that has been so extensively used on the Continent; but I think every one will admit that an instrument which will either print or write, I do not care which, on a column of paper a message in such a form that it can be immediately sent out to the recipient, is far and away in advance of anything we have yet had. I venture to prophesy that we are within a measurable distance of introducing and using instruments of this type. With reference to telephones, Mr. Roberts' remark is a trite and a true one; that is to say, the improvements have been mostly in detail. And, after all, there is no other improvement possible. For a telephone you must have an instrument that you can speak into and hear by. You want a line, and you want switching apparatus which will meet the conditions of switching one subscriber through to another readily. Given these, which are absolutely necessary, all other improvements must be improvements in detail, and I venture to think that the improvements in detail which have been made in telephony within the last four or five years have amounted almost to a revolution. With reference to another criticism that a more extended description might be given in the present paper, as I said before, the paper is rather suggestive than descriptive.

Professor Thompson has referred to the cylinder in Fig. 6. I am not responsible for the engraver, but that was copied almost exactly from a pamphlet that was given to me by the exhibitors at the Paris Exhibition, and it was supposed to describe accurately Slaby's and D'Arco's system. In conclusion I wish to return thanks both on behalf of the Institution and myself, to the proprietors and editors of *The Electrician* and *The Electrical Review* for the loan of all the blocks that are used in illustrating this paper and addendum.

The President. The PRESIDENT: Gentlemen, this is the first meeting of the session.

We have had a most excellent paper, and it has led to a very fine discussion. I propose a vote of thanks to Mr. Gavey for his paper. The President.

The vote of thanks was carried by acclamation.

The PRESIDENT: I will now call upon Mr. Goolden to describe and to demonstrate the use of the Stelje's Type-writing Telegraph.

THE STELJE'S TYPE-WRITING TELEGRAPH.

Mr. W. T. GOOLDEN: The instrument which I have the honour to bring before the notice of this meeting, although it will not have the scientific interest and importance of those which have been described by Mr. Gavey in his paper, will, I think, have some interest for the members. It is the outcome of a very considerable number of years' work. Ever since the first introduction of the Wheatstone A B C telegraph, a large number of people have tried to produce a printed record of messages sent. This instrument, which has been invented during the last few years, has achieved that object, and at both ends of the wire a record of the messages sent is obtained, preventing mistakes which are sometimes made by the original A B C indicator, and also by the telephone, and preventing any dispute as to the actual message which has been sent. The principle underlying the success of this instrument is, I think, the inversion of the method usually adopted. Instead of the current which is sent along the line doing the work of printing, the current merely controls. The mechanism of the work is done by weights or springs. There are two trains of wheels, one actuating an escapement which brings the type-wheel into position, and the other train of wheels which does the actual printing by means of a lever. The printing lever is held up in rather an unusual way by the alternate currents against an electro-magnet, and when the current is stopped the lever allows the printing to take place by means of the weights or springs. A point of interest that I should also like to bring before you, in connection with this, is that this is particularly applicable to telephone lines. We have had a successful trial of this instrument, printing between London and Manchester on a loop line, and we have also found that we can use the instrument while the telephone is actually working without any detriment at all to the neighbouring wires and without any noise on the telephone. Those points you will be able to see for yourselves outside. There is an instrument downstairs in the hall and another one at the top of the stairs to which telephones are attached, and you will see that by means of choke-coils which are placed in the circuit, the two instruments, the telephone and the printing telegraph, can be worked simultaneously without any detriment the one to the other. There is another instrument also outside, the invention of Mr. Higgins, which I do not yet know very much about, so I cannot describe it in great detail, but it appears to work extremely well. You will see it for yourselves.

The PRESIDENT: I will ask you to pass a vote of thanks to Mr. Goolden for this description and also for the demonstration he is about to give downstairs.

The vote was carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Members :

James Franklin.
William Henry Trentham.
Robert Robertson, B.Sc. (Edin.), M.Inst.C.E.

Associate Members :

Leonard James Aron.
Marshall Handyside Bennett.
Robert Beveridge.
John Bowden.
George Dalton Dauncey.
John Lambert.
John Todd Morrison.
Wilfred Ernest Pennefather.
Henry Nicol Thomas.

Foreign Members :

Professor Riccardo Arnò.
Professor Mikail de Châtelain.
Guido Semenza.
William Gordon Thomsen.

Associates :

William James Baker.
George Ernest Cummings.
Arthur Joseph Drakes.
Edward George Fenning.
Wilfred Gaye.
James Olliff Griffits Gibbons.
George Gordon.
Isaac Bridge Hadaway.
Edwin Percy Harvey.
Adam Henry.
Charles Frederick Maxwell Hibberd.
Frank Holland.
Reginald Herbert Kent.
George Kelly Nowlan.
Davidge Page.
William Harry Ridpath.
Frank Harold Rippon.
Edward Lyle Rossiter.
Albert R. Turner.
Harold Wragg.

Students :

Earnest Rosling Alexander.
Denis Robert Howe Browne.
Oswald Henry Browne.
Harry Leslie Churton.
Reginald Cecil Creasey.
Edgar de Lautour.
Charles Henry Fisher.
Robert Benjamin Forster.
Richard Walter Gregory.
Sydney Hubert Harris.
Arthur Lawrence Kavanagh.
Robert Martin Longman.
Frederick Oldham Mills.
Leopold Romero.
Henry William Taylor.
William Bernard Thompson.

GLASGOW LOCAL SECTION.

Paper read at Meeting of Section, November 14th, 1900.

ELECTRICITY SUPPLY.

By W. A. CHAMEN, Member.

This subject has been dealt with so often and by such able hands that the author feels some diffidence in venturing to write a paper upon it. The brief remarks which are now offered, however, will bear only upon two points in connection with the subject, and will naturally take some colour from the particular aspect of the question as applied to the city of Glasgow.

SYSTEM AND PRESSURE OF SUPPLY.

The fact that several undertakings which have commenced with an alternating single-phase high-tension supply have recently been actively engaged in changing their central or nearer areas to low-tension continuous current, supplied direct from dynamos fixed in the generating station without transformation of any kind, must surely be taken as a clear indication that low-tension continuous current is found to be more suitable and more economical for all purposes, where the distance is not so great as to make it too costly in copper. This change has, of course, been brought about by the alteration in the Board of Trade Regulations allowing the use of a pressure in consumers' premises not exceeding 250 volts, and consequently of a three-wire system with a pressure not exceeding 500 volts across the outers.

Mr. Addenbroke, in a very able paper read before this Institution in London a few years ago, foretold this result, and showed that with a favourably selected position of generating station an area measuring five miles in diameter could be economically dealt with by means of low-tension continuous current under these altered conditions. Experience has proved this to be so, and in Glasgow the supply is at present carried on over a radius of two and a half miles

each way from the New Station at Port Dundas. It does not follow, of course, that it will always be economical to work in this way, as the load may grow to such an extent as to warrant putting down other generating stations at the more distant points rather than transmitting many thousands of horse-power through cables from a generating station already fully taxed by a demand of some 20,000 to 30,000 horse-power within a radius of much less than two and a half miles around it.

On the other hand, there may be cases where small amounts of current require to be transmitted to exceptional distances, and in such cases small auxiliary high-tension plants, either continuous or alternating, would seem quite justifiable. The fact, however, that these may be necessary is no reason whatever why the whole generating plant should be made high-tension and current transformed down even in central areas close around the generating station.

The obvious common-sense principle on which to proceed is surely to use simple low-tension direct supply at as high a pressure as possible, and when this fails to meet the case, to supplement with high-tension transmission for the remainder.

A well-known consulting engineer, in a discussion on this subject some three or four years ago, went so far as to admit that this was the right line to go upon, but said that he found the public wanted an alternating-current supply and not a continuous one, and in consequence recommended that low-tension alternators be used for direct supply to the home areas and that step-up transformers be used in connection with this same supply for reaching the outlying districts, thus avoiding the necessity for any kind of separate generating plant for this purpose.

The idea was ingenious, but the author is not aware that any use has been made of it, possibly because it has been found that the public do not, after all, want alternating current.

For supplying motors or arc lighting who would prefer single-phase alternating current to continuous? And for incandescent lighting, what is to be gained by using alternating current?

It may seem to be wasting your time to ask these

questions or to put these arguments before you, but no less a genius than Mr. Ferranti only recently publicly stated his opinion that single-phase alternating current would yet come to be the universally accepted system of supply.

There are, of course, those who say that two-phase or three-phase alternating current of low periodicity will shortly supersede everything else, but in their case the public are not found to want alternating current but continuous, and this is managed by means of rotary converters. The object of this system is said to be to allow the generating station (which for some reason, never yet satisfactorily explained, is bound to contain the whole generating plant of any one undertaking or more if possible) to be situated at a considerable distance from the area of supply, where land is cheap and coal readily obtainable.

In a place like London, where the cost of land within the lighting area is practically prohibitive, where railway accommodation is impossible and the conditions and restrictions arising through the interests of surrounding proprietors most onerous, there is no doubt some reason for adopting such a system; but it is somewhat remarkable that in the case of the Glasgow Tramway power supply, in which this system is being introduced, there was much anxiety to get a site, not as near the coal-pits as possible, but as near the centre of the city as might be.

The site ultimately purchased is about the same distance radially from the centre of the city as the Port Dundas Electricity Supply Works, and figures were given to show both the extra capital which would be involved in going further afield and the annual extra cost through loss in distribution.

Again, it is argued that the weak spot in a continuous-current system is the commutator of the dynamo, but experience has proved that this is an absolutely erroneous idea. Nothing could be more satisfactory than the running of the brushes and commutators of most of the dynamos as now constructed, and, in fact, two- and three-phase alternating systems rely entirely upon commutators in the rotary converters.

The conclusions to which these considerations seem to

point are: (1) That there is no more economical or satisfactory method of supply than low-tension continuous current, generated upon a site or sites, within the area of supply if possible, and supplemented by a small amount of high-tension plant if necessary in order to supply remote corners of the area which may be beyond the reach of low-tension supply. (2) That if it be impossible to find sites within the area at any reasonable price and with railway accommodation and freedom from onerous restrictions due to surrounding proprietors, then a high-tension generating station or stations without the area will be the next best arrangement, though the cost of supply will be increased to some extent.

And it therefore follows that in order to ensure supply at the maximum economy in years to come, sites should be retained in suitable positions within, or as close as possible to the area of supply, and with proper railway accommodation and freedom from hampering restrictions, even at some sacrifice in the interval until they are required.

As regards the exact pressure of supply to consumers, it is obvious that the higher the pressure the more economical will be the distribution, and it must also be clear that where lighting and tramways are supplied from the same generating station it is an advantage to have the pressure for both purposes alike. The pressure allowed by the Board of Trade for tramway supply is 500 volts, and the dynamos are usually constructed to run from 500 to 550 volts for that purpose. These same dynamos will therefore be most suitable, if they are to be used alternatively on lighting mains, for supply on a 500-volt three-wire system, using 250-volt lamps in consumers' premises, with balancers or equalisers to compensate for out-of-balance middle-wire currents. They will allow up to 50 volts drop in feeders at times of heavy load. The Board of Trade Regulations for lighting place the limit for low-tension supply at 250 volts, but although the city of Glasgow has some 1,500 consumers with a maximum load of about 3,000 kilowatts already supplied at this pressure, and the municipalities of Govan and Greenock have also considerable numbers of consumers supplied at the same pressure with complete satisfaction, the Board of Trade are declining to sanction more than 240 volts declared pressure in the London district and elsewhere.

The argument appears to be that the 250-volt limit is one beyond which the pressure must on no account go, and that consequently it cannot be a declared pressure with the margin of variation allowed in another part of their Regulations.

Whatever may be the actual construction to be put upon the words from a legal point of view, surely it is unreasonable and inconsistent to take this line.

The Board of Trade is appointed to look after the interests of the public, but in what way do the public suffer through being supplied at 250 volts? The thing is done, and is an admitted success. It has been in operation in Glasgow for about eighteen months, and no trouble of any kind has arisen in connection with it. There can, therefore, be no scientific or practical reason why it should not be allowed.

The proposal to establish 240 volts means yet another voltage to worry manufacturers and contractors, and through them the public. If the Board of Trade had taken the line of establishing a standard voltage for the benefit of everybody concerned, there would have been some clear object in it, but the result of this decision will be to make at least five different standard voltages—viz., 200, 220, 230, 240, and 250 volts—in use in various places in the kingdom.

On the other hand, to agree upon 250 volts as the maximum declared pressure in consumers' premises would have tended to settle all new work down to this standard, and would have avoided the addition of another voltage to the already too numerous standards in use.

At a time like the present, when standardisation is so much talked about, electrical engineers will do well to give this matter special attention, and if necessary approach the Board of Trade in a body with a view to getting 250 volts sanctioned. It is hard, however, to see what necessity there can really be for taking so much trouble about so small a matter, as all that is required is for the Board of Trade to agree to that reading of Clause 1 in the Regulations for Securing the Safety of the Public, which shall allow 250 volts to be a declared pressure, subject to the variation of four per cent. from that pressure, as laid down in Clause 7 of the Regulations for Ensuring a Proper and Sufficient Supply of Electrical Energy.

Probably the real reason why electrical engineers have not taken any decisive action about this matter is that all the older undertakings are already committed to some other voltage, and will naturally not feel called upon to press for 250 volts when they themselves use 220 or 230, and would not find it worth while to exchange to 250. This, however, is short-sighted policy, and it seems to have resulted in the meantime in the standardisation not of any of the existing voltages, but of another one, viz., 240 for all new work.

In the case of Glasgow, the author of this paper was faced with the problem of converting an existing 200-volt three-wire system into one of a higher pressure, and the question immediately arose as to whether it would be right to be contented with a 400-volt system, using 200-volt lamps in consumers' premises, or to adopt any higher voltage.

While making an alteration, it was clear that if any departure were made from the simple multiple of the existing state of things, additional complications would arise in consumers' premises. The next consideration was whether the advantage to be gained was worth the complication and the cost thereof, and it then became necessary, in order to ascertain what the advantage would be, to settle upon some definite pressure as a basis for calculation. Granting that 250 volts could be used, it meant the difference between a 400- and a 500-volt supply, *i.e.*, an increase of 25 per cent. on the voltage. The value of this increase need not be enlarged upon in a paper addressed to electrical engineers. The advantages to be gained in the way of the saving of copper in the mains and ease of regulation of voltage over considerable distances seemed so great as to make it well worth while to take the step.

Glasgow always wishes to be in the front line, and it certainly would not have been so had it settled down contentedly to a 400-volt three-wire system at the point when it was starting to lay a distribution system, designed rapidly to extend over an area of some twenty-eight square miles. There is no doubt whatever in the author's mind that this alteration to 250 volts was the right step to take, and if the Board of Trade do not think so now, there cannot be the slightest doubt but that they will come to that opinion shortly. It is, however, much to be regretted that in the

meantime other new undertakings should be started in various places at 240 volts instead of 250.

There can be no cause for alarm or for the statement that it is a stretching of the Regulations which will never end, for it must be quite clear to any one that 250 volts is the absolute limit of declared pressure at customers' terminals (apart altogether from motive power supplies which are granted at 500 volts by the special permission of the Board of Trade), and no one could possibly go beyond this figure without deliberately defying the Regulations.

The author holds, of course, that the Regulations as they now stand are perfectly capable of being read so as to allow this 250 volts as a declared pressure, and he doubts very much whether any judge, after hearing arguments, would not decide that the real meaning of the Rules is that 250 volts may be used.

The words of the two clauses upon which the whole argument depends are as follows :—

A.—Pressure of Supply to Consumers.

(1) "The pressure of a supply delivered to any consumer shall not exceed 250 volts at any pair of terminals except with the express approval of the Board of Trade."

B.—Variation of Pressure at Consumers' Terminals.

"The variation of pressure at any consumer's terminals shall not under any conditions of the supply, which the consumer is entitled to receive, exceed 4 per cent. from the declared constant pressure."

For a time a great deal was made of the argument that 250-volt incandescent lamps could not be made satisfactorily. Before deciding upon the matter, therefore, the leading lamp manufacturers were consulted, and they all stated that there would be no difficulty, and that they would be very pleased to take orders for such lamps. For the most part they have been as good as their word, and although some makers have not been quite successful as yet, they will no doubt shortly be able to fall into line with their competitors. Lamps of even five and six candle-power have been in use in Glasgow for over fifteen months past at 250 volts without failure.

The efficiencies of the good lamps now in use are:—

5 and 6 c.p.	5	watts per candle.
8 c.p.	4	" "
16 "	4	" "
32 "	$3\frac{1}{2}$	" "
50 "	$3\frac{1}{4}$	" "

There seems to be but little in the old idea that thin filaments could not be made to last. The leading manufacturers seem to have so far conquered their original difficulties in this respect that even 250 volts does not seem to be the limit to which they can go. Indeed it seems doubtful whether in attempting higher pressures the proximity of the terminals in the present design of lamp would not cause greater trouble than the thinness of the filaments. Up to 250 volts, however, no trouble has occurred in this respect.

There is another possibility to be borne in mind in connection with this matter, and that is the introduction in the near future of the Nernst incandescent lamp. The construction of the filament in this lamp lends itself most readily to the use of 250 or even 500 volts.

The possibilities which lie before us with the Nernst incandescent lamp, giving the necessary light with about half the amount of energy consumed in the present form of lamp, combined with the advantages of the 250-volt supply, are great.

A word may not be out of place on the vexed question of interfering with existing arrangements in some consumers' premises, such as two ordinary open-type arc lamps in series on 100 volts, special small motors for dentists' use, low-voltage heaters and cauteries and such like complications.

One frequently meets the argument that the increase in pressure is all for the benefit of the Corporation, and not for the benefit of the consumer. This argument is of course used by those who think that they will suffer by the change; but they are a very small minority, and do not realise that the object of the change is the cheapening of the supply all round.

It is absurd to talk about "the benefit of the Corporation." Who are the Corporation but the representatives of the people, and whose is the undertaking but the people's? The object of the Corporation is to give that form of supply

which is most economical, and consequently most convenient, for the majority. Electric light has been in the past too much the exclusive light of the rich man, who can well afford to pay a high price and to indulge in every kind of low-voltage complication which suits his own special fancy or convenience; but to maintain low voltage to suit these consumers means to keep up the price and to prevent the great British public from using electric light at all. The benefit of the majority, while at the same time dealing justly with existing consumers in making the change, is what the Corporation aims at. There are no dividends to make, and all profits are used, after providing for the lasting financial soundness of the undertaking, in reducing the price.

The Corporation might have been content to leave things as they were and let the price remain high, but this would have prevented the growth and spread of the undertaking, leaving the supply to those who could afford to pay for it, and whose special and exceptional circumstances it happened to suit.

Most people want light, and they want it in 8, 16, or 32 candle-power lamps. These, therefore, demand the first and most careful consideration. The question is how to supply these at the lowest cost. Having settled that, the other consumers must be made to accommodate themselves to the altered condition of things, and it is surprising, after all, how very little difficulty is experienced in modifying existing appliances to suit the new conditions.

Voltmeters are met with in several houses supplied at 100 volts. They are not readily altered to suit 250 volts, but why should they be allowed to interfere with progress? They are at best most unnecessary and objectionable things for consumers to have. It is a significant fact that it is only in 100-volt supplies as a rule that these voltmeters are found.

In concluding, attention should be drawn to the anomalous position in which the Board of Trade have put the owners of undertakings by allowing them to increase the pressure of supply to all consumers, but only with the consent of such consumers in the case of those supplied previously to the date of the revised Regulations.

In Glasgow common sense has always so far prevailed; but in London it does not seem to have done so, and a mere handful of consumers have in some cases held out against

the change for no apparent reason whatever, except the unpleasant peculiarities of certain kinds of human nature.

A deputation representing some of the London Supply Companies waited upon the President of the Board of Trade about the matter. While admitting that it seemed unfair for a few consumers to have the power of practically upsetting the whole undertaking, the President is reported to have said that the companies should have done more to conciliate the consumers. One cannot help feeling that the companies in London are hardly dealt with. Every improvement they try to make seems to be obstructed by County Council, Board of Trade, or some other body. They are supposed to be doing everything purely for their own selfish gain, and never with the object of improving the conditions for the consumer. Would not the case be very different if the local authorities of London all held the electrical undertakings in their own hands? Would the President of the Board of Trade have made the same remarks if the local authorities had been making the representation before him? Yet the necessity for the change is the same with the companies as with the undertakings in the hands of local authorities.

It is to be hoped that the Board of Trade will give compulsory powers in this matter of change of voltage, subject to arrangement or compensation to be settled by an independent arbitrator.

The local authorities of London may quite possibly be the right parties to own the electricity undertakings, and it is their own fault that they are not so.

Glasgow has realised the importance of the matter, and purchased the original undertaking from Messrs. Muir, Mavor, and Coulson, and more recently the Kelvinside Company's undertaking. The whole of this latter company's consumers have now, with one exception, been changed to the 250-volt supply, and great progress has been made with the change of the old central area. Govan, which is not at present part of Glasgow, has started its own supply at 250 volts, so that if ever it is annexed it will join up with Glasgow without further change. In this way the whole of Glasgow and the adjoining communities are in a fair way to get a universal supply at 250 volts, with the exception of Partick, which is said, under the decision of the Board of

Trade, to be laying down a supply at 240 volts. This is not good, but Glasgow may nevertheless congratulate itself that it is not like London.

Bailie Maclay.

BAILIE MACLAY, convener of the Glasgow Corporation Electricity Committee, said that he was very pleased to be present to hear Mr. Chamen's able paper. They of the Electricity Committee had engaged Mr. Chamen under a deep sense of responsibility, but he thought that anybody who had seen the work that Mr. Chamen had done for them, would agree that they could not possibly have made a better choice. He was very pleased to have heard Mr. Chamen's views expressed to a scientific audience, and from the attention with which they had been followed it was clear to him that he could express himself equally lucidly to a technical audience or to the members of the Electricity Committee.

Mr. W. B. Sayers.

Mr. W. B. SAYERS said that he agreed with Mr. Chamen that continuous current is the most satisfactory supply for a consumer. Beyond the reasons for this given by Mr. Chamen there was the additional reason that continuous-current motors may be made with variable speeds economically. Until recently difficulties of commutation made it impracticable to work a continuous-current motor at anything below its normal excitation without loss of power and destruction of the commutator, but recent improvements had rendered it possible to vary the speed of a motor. This the speaker thought was a very great advantage. Motors which were installed for continuous current might be made to drive a machine not at *nearly* the correct speed but at *exactly* the correct speed. With reference to the question of voltage of supply to consumers and the Board of Trade limitation to 240 volts, it seemed only reasonable that the Board of Trade should allow in the limit of pressure to private consumers the same latitude as they recognise with regard to the "declared" pressure. In other words they would be perfectly consistent if they specified that the limit should not be deemed to be exceeded if the pressure were within four per cent. of 250 volts. This seemed to him (Mr. Sayers) to be the natural and common-sense decision for the Board of Trade to come to on the question.

With regard to Mr. Chamen's reference to the firm of Messrs. Mavor & Coulson, he (Mr. Sayers) did not think that they had been sufficiently remembered for their enterprise and the pecuniary loss they had sustained when their station, mains, etc., were taken over at scrap value. Mr. Mavor had told him of occasions when, seated in his office, watching the arc lamps in a building opposite, his heart would jump with any flicker of the light, lest a hitch had taken place in the supply. Messrs. Muir, Mavor & Coulson's venture was the beginning of the Glasgow public supply, however, and he thought their pioneer work in this connection deserved to be remembered by the citizens of Glasgow.

Mr. Pickstone.

Mr. M. T. PICKSTONE, of Messrs. D. Bruce Peebles & Co., Edinburgh, referred to the variation in voltage required for continuous-current generators. He said this could economically be obtained without sacrificing

Mr. Pickstone.

efficiency to a very large extent. His firm had frequently had to produce generators running with a range of from 400 to 500 volts with constant engine-speed, and in fact it seemed to him that the only point that affected central stations was the question of the lamps, and so far as the station was concerned there was every possible advantage in using a higher pressure.

With reference to the subject of speed variation, he had a conversation with Mr. Chamen about a year ago as to the possibility and extent to which the field of a generator could be weakened and still allow its maximum current to be extracted. Mr. Chamen expressed the opinion that he thought it possible with certain types of machines to weaken the field down to zero and still take the full current without difficulties as to sparking at the commutator. This of course is done to a very great extent in all central stations in connection with the battery-charging boosters; he had, however, been experimenting of late in this direction with the view of utilising it for variable-speed motors, and at that moment his firm had in hand a contract for supplying Messrs. Lloyds, of London, with a printing press motor of 50 H.P. worked on this plan, which is commonly known as the Ward-Leonard system, in conjunction with Messrs. Geipel & Lange.

With this system of motor control it is possible to start the large motor from rest and get a gradual variation in speed up to the full load from zero, the amount of variation between each step merely depending upon the number of contacts on the shunt rheostat used. In the case in point a small motor-generator capable of carrying the full current of a 50-H.P. motor is provided, the generator portion of the motor-generator being provided with a shunt-reversing rheostat. The switchgear for this is exceedingly simple, and merely consists of a starting switch for the motor-generator, a reversing shunt rheostat for the generator portion of the transformer, and a double pole circuit breaker in connection with the large machine. The transformer is first switched on, the generating portion developing 200 volts opposing the voltage of the line, and thus preventing any current from passing through the large motor. On gradually weakening the generator field, the large motor slowly starts from rest with its full current, and the speed is raised by weakening the generator field until this latter is at zero. At this instant the large motor is running at half its full speed, and the generator is carrying its full-load current with no field whatever. Still further to increase the speed of the motor, the shunt of the generator is reversed and the field strengthened up in the opposite direction until the full field in the opposite direction is obtained on the generator. During this latter series of operations the voltage of the generator is strengthening the voltage of the line, so that the large machine has practically 400 volts across it when running at full load. With this system of motor control not only is the switchgear exceedingly simple and compact, but there is no possibility of the motor-man making any mistake regarding it. The efficiency of the whole system is, moreover, exceedingly high, and the writer hopes in the course of a few months to be able to give the Institution a careful series of tests as regards efficiency and regulation of such combinations. This system of course is not new, having

been adopted to some considerable extent in the United States, but it does not appear, for some reason or other, to have been made use of in this country before, and more light is needed for the public to appreciate its manifold advantages. Mr. Pickstone.

Mr. J. M. M. MUNRO: The paper does not offer to deal with the whole subject of electrical distribution, or even exhaustively to review any definite detail of that subject. Mr. Chamen has chosen instead to deal with a few questions, primarily of local interest, but not without very great general importance. He has discussed these with that practical, comprehensive common sense which we have learned to expect from him. The relative advantages of high and low tension for town lighting is a subject which lends itself to endless discussion, as each disputant can select, out of endless possibilities, the conditions favourable to the system he favours, and so have no difficulty in proving that system to be the more economical. But when work is begun in a definite area, facts assert themselves. Mr. Chamen is right, therefore, in considering it a suggestive fact that several towns are changing, or are desirous of changing, from high-tension alternating to low-tension continuous. A considerable part of Mr. Chamen's paper is devoted to defending the pressure of 250 volts adopted in Glasgow, and deprecating the decision of the Board of Trade elsewhere to enforce 240 as a maximum. I am not going to enter on the legal question of the interpretation of the Board of Trade rules. But it is quite within our province to discuss whether there be any practical reason why 250 volts should or should not be a permissible declared pressure. Reasonable objection might be made to this pressure if it could be shown either—(1) That the shorter life and slightly lower efficiency and other practical disadvantages of the 250-volt lamp more than neutralised the economy of generation and distribution due to the difference between 150 volts and any lower pressure. (2) That the risk of leakage, fire, extinction of light, &c., was so increased that the whole system, outdoor and in, could not be made as safe as before without adding so much to the capital expenditure on insulation that the interest and depreciation thereon would neutralise the saving of copper by use of the higher pressure. (The Glasgow installation, as Mr. Chamen has pointed out, belongs to the citizens, so that the sum of the losses of (1) and (2) should be set against the initial saving due to the increased voltage.) (3) That the risk of injury by shock was seriously increased by the increase of potential difference. Mr. Munro

So far as I have been able to make out, after endeavouring to balance these with such figures as I was in a position to obtain, the benefit of using 250 volts amply justified the change from 100 or even 200 volts. It is obvious that a pressure of 240 volts gives nearly all the benefits which may be derived from 250. Why, then, apart from the question of too many standards (for the variety of which the Board of Trade is not altogether responsible), ought we to agitate for a 250-volts standard? My own mind has for many years favoured the adoption of 250 volts as the maximum standard; for these among other reasons—(1) Its double (500–550 volts), the pressure of the outers, is the common standard pressure for tramway work. In most places the supply for

Mr. Pickstone.

efficiency to a very large extent. His firm had frequently had to produce generators running with a range of from 400 to 500 volts with constant engine-speed, and in fact it seemed to him that the only point that affected central stations was the question of the lamps, and so far as the station was concerned there was every possible advantage in using a higher pressure.

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With this system of motor control it is possible to start the large motor from rest and get a gradual variation in speed up to the full load from zero, the amount of variation between each step merely depending upon the number of contacts on the shunt rheostat used. In the case in point a small motor-generator capable of carrying the full current of a 50-H.P. motor is provided, the generator portion of the motor-generator being provided with a shunt-reversing rheostat. The switchgear for this is exceedingly simple, and merely consists of a starting switch for the motor-generator, a reversing shunt rheostat for the generator portion of the transformer, and a double pole circuit breaker in connection with the large machine. The transformer is first switched on, the generating portion developing 200 volts opposing the voltage of the line, and thus preventing any current from passing through the large motor. On gradually weakening the generator field, the large motor slowly starts from rest with its full current, and the speed is raised by weakening the generator field until this latter is at zero. At this instant the large motor is running at half its full speed, and the generator is carrying its full-load current with no field whatever. Still further to increase the speed of the motor, the shunt of the generator is reversed and the field strengthened up in the opposite direction until the full field in the opposite direction is obtained on the generator. During this latter series of operations the voltage of the generator is strengthening the voltage of the line, so that the large machine has practically 400 volts across it when running at full load. With this system of motor control not only is the switchgear exceedingly simple and compact, but there is no possibility of the motor-man making any mistake regarding it. The efficiency of the whole system is, moreover, exceedingly high, and the writer hopes in the course of a few months to be able to give the Institution a careful series of tests as regards efficiency and regulation of such combinations. This system of course is not new, having

been adopted to some considerable extent in the United States, but it does not appear, for some reason or other, to have been made use of in this country before, and more light is needed for the public to appreciate its manifold advantages. Mr. Pickstone.

Mr. J. M. M. MUNRO: The paper does not offer to deal with the whole subject of electrical distribution, or even exhaustively to review any definite detail of that subject. Mr. Chamen has chosen instead to deal with a few questions, primarily of local interest, but not without very great general importance. He has discussed these with that practical, comprehensive common sense which we have learned to expect from him. The relative advantages of high and low tension for town lighting is a subject which lends itself to endless discussion, as each disputant can select, out of endless possibilities, the conditions favourable to the system he favours, and so have no difficulty in proving that system to be the more economical. But when work is begun in a definite area, facts assert themselves. Mr. Chamen is right, therefore, in considering it a suggestive fact that several towns are changing, or are desirous of changing, from high-tension alternating to low-tension continuous. A considerable part of Mr. Chamen's paper is devoted to defending the pressure of 250 volts adopted in Glasgow, and deprecating the decision of the Board of Trade elsewhere to enforce 240 as a maximum. I am not going to enter on the legal question of the interpretation of the Board of Trade rules. But it is quite within our province to discuss whether there be any practical reason why 250 volts should or should not be a permissible declared pressure. Reasonable objection might be made to this pressure if it could be shown either—(1) That the shorter life and slightly lower efficiency and other practical disadvantages of the 250-volt lamp more than neutralised the economy of generation and distribution due to the difference between 150 volts and any lower pressure. (2) That the risk of leakage, fire, extinction of light, &c., was so increased that the whole system, outdoor and in, could not be made as safe as before without adding so much to the capital expenditure on insulation that the interest and depreciation thereon would neutralise the saving of copper by use of the higher pressure. (The Glasgow installation, as Mr. Chamen has pointed out, belongs to the citizens, so that the sum of the losses of (1) and (2) should be set against the initial saving due to the increased voltage.) (3) That the risk of injury by shock was seriously increased by the increase of potential difference. Mr. Munro

So far as I have been able to make out, after endeavouring to balance these with such figures as I was in a position to obtain, the benefit of using 250 volts amply justified the change from 100 or even 200 volts. It is obvious that a pressure of 240 volts gives nearly all the benefits which may be derived from 250. Why, then, apart from the question of too many standards (for the variety of which the Board of Trade is not altogether responsible), ought we to agitate for a 250-volts standard? My own mind has for many years favoured the adoption of 250 volts as the maximum standard; for these among other reasons—(1) Its double (500–550 volts), the pressure of the outers, is the common standard pressure for tramway work. In most places the supply for

Mr. Munro. tramways and lighting can be with advantage combined under one management, and it is as well to have as many parts as possible interchangeable between the two. (2) The pressure of 500–550 volts is about the limit of safe pressure for physiological reasons. At this pressure shock is unpleasant. We have all heard of injury to people by much less than 500 volts, but we also know of many who have received 500-volt shocks without harm. Much of course depends on the route of the current through the body, the resistance of the contact made, and the condition of the recipient both as regards mind and body. In any case a pressure of 500 volts appears to be about the safe limit under ordinary conditions. (3) A less important reason is that 250–500 are conveniently round figures. (4) I might add a fourth reason that with pressures over 250 volts switches and minor appliances need to be somewhat clumsy to get safety distance between parts.

I have no doubt that it will in time be necessary to add to the number and proximity of Glasgow supply stations. I am sorry the new Electric Tramway Station was not farther from the Electric Light Station at Port Dundas—much farther, or a great deal nearer—that is, under one roof.

For long-distance transmission, the various forms of alternating high-tension current may be, and are, successfully employed. Something has been attempted in this country, and more will be done, in the direction of sending power from where it is cheap to where it is dear. For electric railway work alone, on other than short, isolated lines, there is a great future for transmission at high pressure, with transformation down to working pressures of 500 volts for polyphase motors, as well as by transformation to continuous current at like pressures for lines having many stopping-places close together.

Lord Kelvin. LORD KELVIN asked Mr. Chamen if it was possible to increase the pressure of an installation from, say, 200 volts to 250 volts by simply increasing the speed of the engines and dynamos. He wished to know if the fittings now in use for 100 or 200 volts were suitable for 250 volts. Lord Kelvin had himself said some years ago that he did not think it would be safe to allow a higher pressure than 300 volts inside a consumer's premises. His Lordship also made interesting reference to the development of the incandescent lamp by Swan and Edison. He mentioned that Swan had started by making lamps at 45 volts pressure, and that Edison had doubled this pressure, making his lamps suitable for 100 volts. Since then the pressure of supply had gradually risen, and he was pleased to know that satisfactory 250-volt lamps could now be made.

Mr. Ionides. MR. P. D. IONIDES, of the Westinghouse Company, made brief reference to the flexibility of a three-phase transmission and distribution.

Mr. Mavor. MR. SAM MAVOR, referring to Mr. Sayers' remarks, wished to acknowledge the very generous recognition which Mr. Chamen had always accorded to Messrs. Muir, Mavor & Coulson's pioneer work in the Public Electric Supply for Glasgow. Mr. Chamen had earned great credit for his courage in taking the initiative in boldly adopting the maximum pressure allowed by the Board of Trade, and in facing

not only such technical difficulties as existed but also the uncertainties involved in his interpretation of an ambiguous clause in the Board of Trade Regulations. That Mr. Chamen's rendering of the clause was the common-sense one the speaker had no doubt, and he was glad to hear that Lord Kelvin gave the weight of his authority in support of this interpretation. Mr. Mavor.

Bailie Maclay had referred to the Corporation's good fortune in having the professional advice of Lord Kelvin at the critical time when the electric lighting undertaking was absorbed, and especially to the advice which led to the adoption of the low-tension system. Although it was now ancient history, the speaker reminded Lord Kelvin that Messrs. Muir, Mavor & Coulson also had the privilege of his advice and were in a position, with his Lordship's support, to inform the Corporation that whatever might be the best course for *them* to follow, the high-tension alternating system of distribution was the only commercially possible one by which the pioneer work could have been carried out, and it was therefore the right one for Muir, Mavor & Coulson to adopt. In valuing the high-tension plant, however, the Corporation omitted to value the business it had made; but the value of the business they then took over has since dawned upon them.

Professor M. MACLEAN gave two tables showing the pressure of supply in 90 low-tension stations and in 75 high-pressure stations in this country. Of 90 low-pressure continuous-current stations he found that there were— Professor Maclean.

10 at	100 volts	declared	pressure.	
1 „	107	„	„	(St. James' Parish).
1 „	113	„	„	(Leamington).
4 „	110	„	„	
4 „	150	„	„	
13 „	200	„	„	
15 „	210	„	„	
24 „	220	„	„	
14 „	230	„	„	
1 „	240	„	„	
3 „	250	„	„	namely—(*a*) Glasgow, (*b*) Greenock, and (*c*) Govan.

but of 75 high-pressure alternating current stations there were—

28	working at	100 volts	pressure.	
2	„	102	„	
1	„	105	„	
35	„	200	„	
2	„	205	„	
2	„	210	„	
3	„	220	„	
1	„	230	„	
1	„	250	„	(Bristol).

Mr. JAMES COATS (*communicated*): With reference to the number of Mr. Coats.

Mr. Coats. electric supply companies using high-voltage continuous current, Dr. Magnus Maclean mentioned there were only three of 250 volts, viz., Glasgow, Govan and Greenock. I may mention, however, that the Scottish Co-operative Wholesale Society, Limited, of Glasgow (while not a public supply company, yet having a larger output than many public companies), were among the first in Scotland to adopt the higher pressures. It is now about five years since I observed the St. Pancras Vestry had raised their voltage to 220—Glasgow at that time being 100 volts. About that time I laid down a fair-sized lighting installation at a pressure of 220 volts, which has now been working for four years without having to renew a switch. Two years ago a larger installation was required for lighting and transmission of power in connection with six large factories, having over 30 motors ranging from $\frac{1}{6}$ H.P. to to 20 H.P. I decided to follow on the lines of Mr. Chamen, and the plant accordingly was laid down for 250 volts. This has now been running for sixteen months amongst all classes of workpeople, male and female, and so far everything has been very satisfactory. Apart from the considerable saving in the cables my main object in going up to this voltage was to be in keeping with the Glasgow Corporation supply, so that there should be no difficulty in changing over at any time that the Corporation were able to supply the current cheaper than we could produce it. It seems to me it is most absurd for the Board of Trade to issue vague regulations, which apparently can only be read by lawyers.

Mr. McWhirter. Mr. WILLIAM McWHIRTER (*communicated*): I must first of all congratulate the Glasgow Local Section on having a paper brought before them dealing so admirably with electricity supply so far as Glasgow is concerned. With the arguments put forward by Mr. Chamen in favour of low-tension continuous current, as against alternating high tension, in compact areas I think every one must agree, it is surprising, in face of all the experience gained with low-tension working, that even now engineers are to be found who have the courage to advise the adoption of alternating currents in such areas.

No fault can be found with Mr. Chamen's decision to adopt the full pressure allowed by the Board of Trade, and in my opinion it is a grievous mistake that the Board of Trade should now step in to make an alteration of only a few volts, which, however, are sufficient to interfere with what was most likely in the future to be a universal standard of pressure, viz., 500 volts on a three-wire system. Surely the time is come when the electrical trades should take up a position and bring pressure to bear upon the Board of Trade in such a way that so unreasonable a proposal as this alteration should not take effect. Other trades and industries have had before now to bring such pressure to bear upon a Government department, and surely now is the time for the electrical industry to be up and doing. Supposing the Board of Trade argument to be that 500 volts *plus* the drop in the feeders is dangerous, then surely one and all will admit that 500 volts cannot be safe. That being so, it is much the same as allowing an alternating-current supply at 1,000 volts, but refusing to pass it at 10,000 volts. Mr. Chamen uses a very clever argument in favour of

the increased pressure when he defines "who are the Corporation." There is no doubt whatever that with all deference to such an authority the pressure of 250 volts is not so convenient for the user as a rule, but at the same time there is every prospect that this will be only a temporary objection, as no doubt very shortly lamps will be found (especially arc lamps) which will work as well, and as economically, on the higher pressure as they have hitherto on the lower. Failing this there is no reason why the reduced price of electricity when used in motors should not be utilised in many instances for driving small motor generators, and so getting the pressure that may be found most convenient. Mr. McWhirter.

In conclusion I have to join in thanking Mr. Chamen most heartily for the splendid paper he has brought before the meeting.

Mr. W. A. CHAMEN, in reply to the discussion, said that the only difficulty in making a change of pressure lay in the consumers' installations. Even if incandescent lamps were a little less efficient at the higher voltage, that had been taken into account by Mr. Addenbroke in the paper referred to, and there was still a considerable balance in favour of the high pressure as regarded cost of lighting, because the price of current could be so much reduced. Mr. Chamen.

Experience had not shown that there was any greater risk of fire with 250 volts than with 100 volts. What had certainly given him some trouble with bad installations (often new ones) was the fact that the middle wire of the 250-volt system was earthed.

This caused small outbreaks of fire sometimes by fusing compo gas-pipes and setting the gas on fire.

The risk of accident by shock was nothing, but it had often struck him as strange that while the Board of Trade were so anxious lest the public should get shocks they seemed perfectly indifferent about the risk of burning people alive in their own houses. That question appeared to be the business of some one else.

As regarded the question why 250 volts should be maintained as against 240, which the Board of Trade were prepared to sanction, it must be remembered that at the time 250 volts was made use of in Glasgow there was nothing above 230 in use elsewhere. Two hundred and forty volts had not been suggested by any one, and the Board of Trade had deliberately made that fresh standard after Glasgow had already started and succeeded with a 250-volt supply.

In answer to Lord Kelvin's questions it was generally found that the lamp-holders and switches were quite good for use with the increased pressure on installations which had been put in during the last four or five years.

There were, however, some lamp-holders of ancient date still found in use occasionally, and also some open switches without covers, which had to be replaced. Generally speaking any good make of switch with a quick break would work quite well under the increased pressure so long as there was no increase made in the number of lamps controlled by it.

Dynamos constructed to run at 220 volts could quite well be run up to 250 volts as a rule, but the difficulty arose not so much with the

Mr. Chamen dynamos as with the engines which might not so well stand the extra speed.

He was sorry that Mr. Ionides had been alone in the defence of multiphase current supplies, and thought he ought to have been better supported. No doubt multiphase current could be utilised for driving variable speed motors to some extent, and also for electric furnaces, but there did not appear to be any particular advantage in the use of it, even for these purposes, and it must be remembered that the main question now under consideration was the general supply of electricity for lighting firstly, and then for any other purposes which might be made to fit in.

With regard to the question of costs it must be remembered that no fine economy had been possible in Glasgow for some time past, where the supply had to be carried on under conditions of great difficulty in works under construction.

JOURNAL

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The Three Hundred and Fifty-Second Ordinary General Meeting of the Institution was held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, on Thursday evening, November 29th, 1900—Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on November 22nd, 1900, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that these names should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Thomas Ernest Herbert.

From the class of Students to that of Associates—

John Frank Auguste Margetts.

Messrs. J. H. Johnson and S. J. Clay were appointed scrutineers of the ballot for the election of new members.

A donation to the Library was announced as having been received since the last meeting from Société Anonyme John Cockerill, and to the *Building Fund* from Mr. James Kynoch, to whom the thanks of the meeting were duly accorded.

The PRESIDENT : I have to announce that on the 18th of December a Reception will be held at the Covent Garden Opera House, which has been most kindly lent for the

purpose by the Managers, Mr. Rendle and Mr. Forsyth. The Institution will then, assisted by the Corps of Electrical Engineers, Royal Engineers, Volunteers, receive the Active Service Contingent of that Corps on its return from South Africa. The 18th of December has been chosen because, although the return of the South African Detachment is, I believe, announced for the 8th or 9th of that month, there are delays in ships, and we felt it was well to have a safe date. Notices will be sent to members in the ordinary course.

I will now ask Mr. Langdon, Vice-President, to read his paper.

ON THE SUPERSESSION OF THE STEAM BY THE ELECTRIC LOCOMOTIVE.

By W. LANGDON, Vice-President.

Probably one of the most interesting questions associated with the application of electrical energy to railway work is its eventual supersession of the steam locomotive. Electric locomotives of a capacity equal to that of the steam locomotive, doing similar work, and possessing certain marked advantages, are an accomplished fact, and to many it may seem that the days of the steam locomotive are numbered. We must not, however, forget that that which has been done has its *raison d'être.* Its employment has hitherto been generally confined to localities where the effects of steam and smoke would exercise a baneful influence. Because it has been so employed, and its employment has been attended with such marked success, it does not follow, however much it may appear desirable, that in overland lines of railway electricity will in future prove to be the element of power. Railways are commercial undertakings, in which vast sums of money have been embarked, all of which, investors expect, will produce a certain annual return. The supersession of the steam by the electric locomotive thus resolves itself, primarily, into one of profit and loss. If its adoption will enable railways to be worked more economically than is the case under steam, then it will, with its attendant advantages, sooner or later, be adopted—if not by the whole, certainly by the greater portion of the railways of

this country; but, whatever the ulterior advantages may be, unattended by this result, its adoption will remain doubtful.

The first question to be asked is: Are we in a position to consider the subject? Is the data at our disposal such as to admit of a reasonable treatment of it? The primary factors are well known. We know how many pounds of steam we can obtain from a given quantity of coal. The efficiencies of prime movers and electrical generators, the loss in transmission, transformation, and distribution are all determinable. Any advantages yet to come must be looked for in the steam generator and in the simplification and consequent ultimate increase of efficiency in the electrical apparatus. In each, no doubt, the future will see production cheapened. Labour may advance, but competition will grow, and in the price of the manufactured article we may reasonably look to the future to produce some advantage.

Having then the material at hand, it is reasonable to conclude that the consideration of the subject can only be attended with good; for, if it should be shown that advantage is to be anticipated from such a change, it will help us to grasp that which has to be attempted, and perhaps to evolve from the data at our disposal the course most desirable to follow.

The railways of the United Kingdom comprised on the 31st of December, 1899,[1] the following mileage of line:—

Double Line or more	11,977
Single Line	9,723
Total mileage	21,700

The number of locomotives employed for working these railways was 20,461. The total number of vehicles of all descriptions was rendered as 752,930. The year's cost for locomotive power, including stationary engines, was £16,491,377. The number of miles travelled by trains was 396,241,265. Number of passengers—exclusive of season tickets—1,106,691,991. The tonnage of minerals, 296,611,190; and of general merchandise, 117,011,835.

In dealing with a question of this nature it seems

[1] Board of Trade Railway Returns, 1899.

desirable to produce these figures; but they are, in fact, except to afford some idea of the magnitude of the subject, of very little use. The length of the passenger journeys is not stated, nor are the journeys taken by season ticket holders included. To be of value the per passenger mileage, including of course the journeys made by season ticket holders, should be given. The same objection applies to the mineral and goods tonnage statement. It records the tonnage declared as placed upon the railway, but whether it is carried one mile or one hundred miles is not shown. In fact the returns, as rendered, aid the consideration of the subject very little; and I am sorry to say the information in the hands of the railway companies themselves carries us no further.

Under these circumstances, the establishment of a common basis upon which to consider the relative cost presents much difficulty. The only manner in which it can be approached is by averaging the data obtainable, or by examining the work of a particular section of line.

In Table I., I furnish extracts from the Board of Trade Returns for the year 1899, showing the mileage of line, cost of locomotive power, train mileage worked, &c., for England and Wales, Scotland and Ireland, together with certain deductions therefrom applicable to these results; as also similar data in reference to six of the most important English companies.

In considering the mileage of line quoted, it should be metioned that the figures do not disclose the *mileage of roads.* Over many sections of the several lines of railway there are more than two roads. Most main routes working out of London possess four, and even six roads, for a considerable distance; and the same applies to other busy portions of the chief railway systems.

The table indicated shows that the cost of locomotive power for the United Kingdom, including stationary engines for pumping and other purposes, works out at 9·988 pence per train mile. That the cost for England and Wales is 10·253; for Scotland 8·862; and for Ireland 8·104 pence. And that this cost varies with the several companies quoted as follows:—London and North-Western, 9·477 pence; London and South-Western, 9·844; Great Northern, 9·892; Great Western, 9·905; Midland, 10·218; and North-Eastern, 12·266—their average cost being 10·267.

TABLE I.

MILEAGE OF LINE, COST OF LOCOMOTIVE POWER, TRAIN MILEAGE, ETC.,

For Year Ending December 31, 1899.

	Length of Line in Miles open on 31st December, 1899.			Cost of Locomotive Power, including Stationary Engines.	No. of Locomotives.	Number of Miles Travelled by Trains.			(h) Cost per Train-mile for Locomotive Power. $\frac{c}{g}$	(k) Number of Miles Travelled by Trains per hour during year of 365 days. $\frac{g}{8,760}$	(l) Number of Trains per Mile per hour (365 days to the year.) $\frac{k}{b}$
(a)	Double or more.	Single.	Total. (b)	(c)	(d)	By Passenger Trains. (e)	By Goods and Minerals. (f)	Total. (g)			
				£					Pence.		
England and Wales	9,933	5,111	15,044	14,101,842	17,411	178,684,803	151,377,966	330,062,769	10·253	37,678	2·505
Scotland	1,423	2,057	3,480	1,811,552	2,241	27,588,633	21,473,089	49,061,722	8·862	5,601	1·609
Ireland	621	2,555	3,176	577,983	809	10,367,617	6,749,157	17,116,774	8·104	1,954	0·615
Total—United Kingdom...	11,977	9,723	21,700	16,401,377	20,461	216,641,053	179,600,212	396,241,265	9·988 Average.	45,233	2·084 Average.
				RAILWAY COMPANIES.							
				£					Pence.		
Great Northern			825	995,690	1,259	11,729,522	12,426,497	24,156,019	9·892	2,757	3·3
Great Western			2,602	1,884,032	1,933	23,085,687	22,561,470	45,647,157	9·905	5,210	2·0
London and North-Western			1,924	1,927,049	2,959	26,285,278	22,515,697	48,800,975	9·477	5,570	2·9
London and South-Western			900	709,110	728	12,598,390	4,689,644	17,288,034	9·844	1,973	2·2
Midland			1,431	2,016,816	2,507	18,979,594	28,387,090	47,366,684	10·218	5,407	3·7
North-Eastern			1,632	1,632,967	2,047	14,641,572	17,307,802	31,949,374	12·266	3,647	2·2
									Average 10·267		

Column *l* indicates the number of trains, per mile per hour, based upon the mileage of line of railway shown by the returns. Bearing in mind that there are, over many portions of the railways indicated, several lines, or roads, the number of trains travelling per mile per hour is, perhaps, surprisingly small. Ireland claims but 0·615; Scotland, 1·609; England and Wales, 2·505. Of the railways individualised, the Great Western has an average of but 2; the London and South-Western and the North-Eastern each 2·2; London and North-Western, 2·9; Great Northern, 3·3; and the Midland, 3·7 (that is, the Midland, for instance, has, on an average, 3·7 trains passing over each *mile of line of railway*, each hour; not that the mile of line is occupied by these 3·7 trains during the entire hour, but that that is the average number of trains worked over the mile of line of railway—quite irrespective of the number of lines of rails—within that period of time).

If trains were, in practice, so distributed, this might form a basis on which to found a comparison of cost for the entire railway system; but we know that this is not so—that trains are much more frequent on certain portions and less frequent on other portions of the lines of railway, and although it is a kind of basis, affording some very interesting figures, it is not, as it stands, a practical one for the purpose in view. To effect this it is necessary to consider the work of an individual section of some line of railway; and with this view I have taken that portion of the Midland Company's main line between London (St. Pancras) and Bedford—omitting the suburban and local traffic applicable to the Metropolitan and Tottenham lines.

The length of line of railway is 49·5 miles—practically 50 miles; and the number of lines of rails applicable to the traffic under consideration may be taken as four—it is not less. In order to ascertain the number and character of trains to be taken into consideration, I have obtained returns (Tables II. and III.) extracted from the Block Book, of those trains passing two points—Luton and Harpenden—each hour, during a day of twenty-four hours in the month of July, 1900, which I have summarised and classified so as to bring the subject within reasonable scope. These details are carried forward to Table IV., which forms the basis of

calculation for comparison of cost for power to work the traffic indicated.

TABLE II.

LUTON.

Statement of the Number of Trains recorded in the Block Book for the 24 hours ending midnight on Thursday, July 19, 1900.

Hours.	Express Passenger.	Ordinary Passenger.	Coaches.	Fish and Milk.	Express Goods. Class "A."	Express Goods. Class "B."	Ordinary Goods.	Minerals.	Light Engines.	Total number of Trains each hour.
12 to 1 a.m. ...	2	—	—	—	1	5	—	3	—	11
1 ,, 2 ,, ...	—	—	1	—	—	10	—	2	—	13
2 ,, 3 ,, ...	—	—	1	3	1	3	—	5	—	13
3 ,, 4 ,, ...	1	—	—	—	—	3	—	6	—	10
4 ,, 5 ,, ...	1	—	—	—	3	5	—	6	—	15
5 ,, 6 ,, ...	2	—	—	—	2	4	1	2	—	11
6 ,, 7 ,, ...	1	1	—	—	3	—	1	5	—	11
7 ,, 8 ,, ...	1	1	4	—	2	4	1	3	—	16
8 ,, 9 ,, ...	1	1	—	—	1	2	—	2	—	7
9 ,, 10 ,, ...	4	—	—	—	—	2	—	4	—	10
10 ,, 11 ,, ...	4	1	—	—	—	1	1	4	—	11
11 ,, 12 (noon) ...	3	—	—	—	1	1	1	3	—	9
12 ,, 1 p.m. ...	4	1	—	—	—	1	2	5	—	13
1 ,, 2 ,, ...	4	1	1	—	—	2	—	4	—	12
2 ,, 3 ,, ...	6	2	3	—	—	—	—	8	—	19
3 ,, 4 ,, ...	2	3	—	—	1	—	3	5	—	14
4 ,, 5 ,, ...	4	—	1	—	—	—	1	5	—	11
5 ,, 6 ,, ...	4	2	—	—	—	—	2	3	—	11
6 ,, 7 ,, ...	5	1	—	—	—	—	—	4	—	10
7 ,, 8 ,, ...	4	2	1	—	—	—	—	5	—	12
8 ,, 9 ,, ...	—	2	1	—	3	—	—	1	—	7
9 ,, 10 ,, ...	2	—	—	—	1	2	—	4	—	9
10 ,, 11 ,, ...	5	2	—	—	—	—	2	7	—	16
11 ,, 12 (midnight)	2	1	2	—	1	6	3	1	—	16

CLASSIFICATION.

Express Passenger...				62
Ordinary Passenger		21	36	
Coaches		15		
Fish and Milk		3	74	
Express Goods—Class "A."	20	71		
,, Class "B."	51			
Ordinary Goods		18	115	
Minerals		97		

Total number of Trains during the 24 hours ... 287

Maximum number of Trains in 1 hour 19
Minimum ,, ,, ,, ... 7

TABLE III.

HARPENDEN.

Statement of the Number of Trains recorded in the Block Book for the 24 hours ending midnight on Thursday, July 19, 1900.

Hours.	Express Passenger.	Ordinary Passenger.	Coaches.	Fish and Milk.	Express Goods. Class "A."	Express Goods. Class "B."	Ordinary Goods.	Minerals.	Light Engines.	Total number of Trains each hour.
12 to 1 a.m. ...	2	—	—	—	3	3	1	4	—	13
1 „ 2 „ ...	—	—	1	—	—	9	2	2	—	14
2 „ 3 „ ...	—	—	1	3	1	3	2	1	—	11
3 „ 4 „ ...	—	—	—	—	2	3	3	3	—	11
4 „ 5 „ ...	1	—	—	—	2	5	4	1	—	13
5 „ 6 „ ...	3	1	—	—	2	4	2	1	1	14
6 „ 7 „ ...	—	—	—	—	—	2	5	1	1	9
7 „ 8 „ ...	2	3	2	—	2	5	—	—	1	15
8 „ 9 „ ...	4	1	—	—	1	—	5	3	—	14
9 „ 10 „ ...	5	2	—	—	—	1	3	1	—	12
10 „ 11 „ ...	3	1	—	—	1	1	—	1	—	7
11 „ 12 (noon) ...	5	—	—	—	—	2	2	2	—	11
12 „ 1 p.m. ...	5	2	1	—	—	1	1	2	—	12
1 „ 2 „ ...	3	2	—	—	—	1	6	3	1	16
2 „ 3 „ ...	5	3	1	—	—	1	3	2	1	16
3 „ 4 „ ...	4	1	1	—	—	1	2	3	1	13
4 „ 5 „ ...	3	5	—	—	—	—	2	2	—	12
5 „ 6 „ ...	5	1	—	—	—	—	2	2	—	10
6 „ 7 „ ...	3	1	—	—	—	—	2	2	1	9
7 „ 8 „ ...	6	2	—	—	2	—	1	—	—	11
8 „ 9 „ ...	2	3	—	—	1	2	1	3	1	13
9 „ 10 „ ...	3	2	—	—	—	3	3	3	1	15
10 „ 11 „ ...	3	2	—	1	1	1	1	2	1	12
11 „ 12 (midnight)	—	1	1	—	4	4	2	2	—	14

CLASSIFICATION.

Express Passenger			67
Ordinary Passenger		33	41
Coaches		8	
Fish and Milk		4	78
Express Goods—Class "A."	22	74	
„ „ Class "B."	52		
Ordinary Goods		55	111
Minerals		46	
Light Engines		10	

Total number of Trains during the 24 hours ... 297

Maximum number of Trains in 1 hour... 16

Minimum „ „ „ 7

TABLE IV.

BASIS OF CALCULATION.

Showing Number of Trains, classified, passing certain points of a 50-mile Section of Line of Railway; calculated Mechanical Horse-power and Electrical power for working the same, together with apportioned speed, load, etc.

Class of Train.	No. of Trains per Day of 24 hours passing.		Basis of Calculation.							Total.	
	Luton.	Harpenden.	Apportioned No. of Trains per hour.	Speed. Miles per hour.	Train Miles per hour.	Load, including Engine. Tons.	Total Tractive Effort per Train. lbs.*	Mechanical H.P. per Train.	Equivalent in K.W. hours.	Mechanical H.P. per hour.	Equivalent in K.W. per hour.
1. Express Passenger	62	67	3	50	150	275	3,575	477	356	1,431	1,068
2. Ordinary Passenger and Empty Coaches	36	41	2	32	64	300	2,130	182	136	364	272
3. Express Goods and Perishables	74	78	4	35	140	400	3,160	295	220	1,180	880
4. Ordinary Goods and Minerals	115	111	5	25	125	500	2,750	183	137	915	685
Totals	287	297	14		479					3,890	2,005
Average per hour	11·9	12·4									

Tractive effort, lbs., per ton $= 3 + \frac{V^2}{250}$ where V = speed in miles per hour. * Tractive effort × load tons = Total tractive effort per train.

$$\text{H.P.} = \frac{\text{Tractive effort lbs.} \times \text{miles per hour.}}{375}$$

The classification adopted is necessarily somewhat arbitrary, but in its construction I have endeavoured to err on

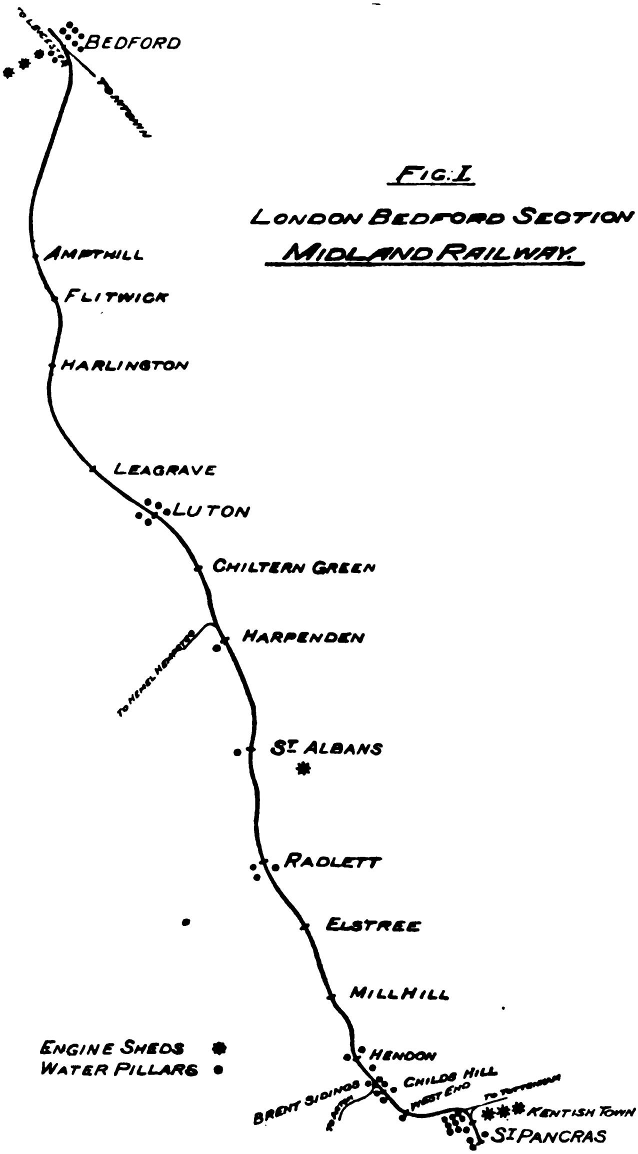


FIG. I
LONDON BEDFORD SECTION
MIDLAND RAILWAY.

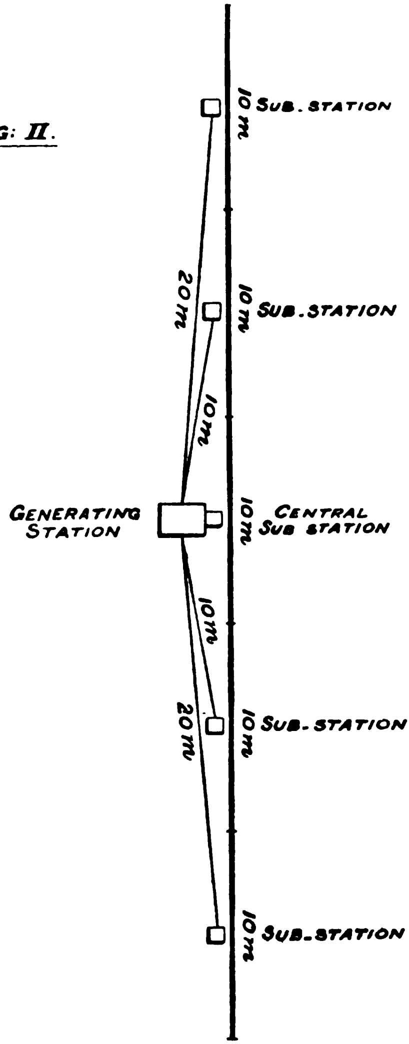
the right side—for instance I have debited each train of its class as a loaded train, whereas some would certainly be

light trains. Again I have, I believe, accorded to each their full merit of speed, although there is reason to assume that, in many instances, certain goods and minerals would not observe that allotted to them. From this table we get the tractive effort per train, and the consequent mechanical and electrical power required to deal with *one hour's work*. The work may, and of course does, vary from one hour to another; indeed, that is clearly shown by Tables II. and III.; for instance, the trains passing Harpenden vary per hour from 7 to 16, and Luton from 7 to 19, but the section of line chosen may be regarded as a full line, a line well occupied by trains both night and day, Sundays and week-days. The returns show an average of 11·9 trains passing Luton and of 12·4 passing Harpenden, per hour. In taking an average, however, I have apportioned no less than 14 trains to the hour. This number divided between the four lines of metals gives a result of 3·5 trains per mile per hour, per line of metals. It may here, however, be as well to point out that, so long as the appropriated number of trains is fairly that in practice, the number applied is, for comparison purposes, immaterial, for the comparison I draw is based upon the train mileage cost.

Fig. 1 illustrates the section of line under consideration. The position of engine-sheds is shown by stars (*); of water-cranes by dots (•). The short or suburban traffic between St. Pancras and Hendon, and the Tottenham line, &c., is not included in my schedules, for the reason that, viewing the section of line as if actually subject to electrical working, there would be little doubt that this immediate London-Suburban traffic would demand a generating station nearer home than that indicated in the scheme I have adopted as my basis for the comparison of costs for working a 50-mile section of line.

The Plant scheme is roughly outlined in Fig. 2. Midway in the 50 miles of railway is the central station, containing four 2,500 kilowatt, three-phase, or other characteristic, 10,000 volt generators. At this pressure current is distributed to substations, each serving 10 miles of railway, where the potential is converted to 600, from whence it is carried to the contact-rail. Or the centre 10-mile section may be provided for by direct-current generators served from the same steam plant.

FIG: II.



The efficiencies of the various parts are assumed as follows :—

	Loss. Per cent.	Efficiency.
Motors	15 ...	·85
Ohmic loss in rails ...	10 ...	·90
Leakage	2½ ...	·975
Rotary converters ...	10 ...	·90
Static transformers ...	7 ...	·93
H.T. transmission ...	10 ...	·90

The total kilowatts required on the train-wheels (Table IV.) is 2,905 per hour, and the number of trains is 14. Therefore $\left(\frac{2{,}905}{14}\right)$ 207·5 will be the average kilowatts per train hour; and, assuming the efficiency of the motors at 85 per cent., $\left(\frac{207 \cdot 5}{\cdot 85}\right)$ 244 kilowatts will be the average power required to be supplied to each train. If now we allow 10 per cent. loss in the rails which supply and return the current, a pressure of 540 only will be available at either end of a section of 10 miles. Therefore the amperes per train that will be required will be $\left(\frac{244 \times 1{,}000}{540}\right)$ 452.

As there are 14 trains per hour in the total 50 miles section, there will be $\frac{14}{5} = 2 \cdot 8$, say 3 trains in one section of 10 miles to be supplied by one substation.

$$452 \times 3 = 1{,}356 \text{ amperes.}$$

Adding $2\frac{1}{2}$ per cent. for leakage, we have 1,390 amperes as the current to be supplied by each substation at 600 volts.

The efficiency of the converters and static transformers is taken at, respectively, 90 per cent. and 93 per cent., and the three-phase transmission at 90 per cent.

$\therefore \frac{1{,}390 \times 600}{1{,}000 \times \cdot 9 \times \cdot 93 \times \cdot 9} = 1{,}107$ k.w. to be delivered to the trains for each section containing 3 trains.

As there are 14 trains, there will be 4 sections with 3 each, and 1 section with 2 trains.

Now the 4 sections with 3 trains each would require—

$$1{,}107 \times 4 = 4{,}428 \text{ kilowatts.}$$

To allow for the maximum loss let it be assumed that the centre 10-mile section, which as previously indicated might be supplied direct at 600 volts, is so dealt with, and that it is the section that has two trains only.

The kilowatts required would equal—

$$\frac{1{,}390 \times 600}{1{,}000} \times \frac{2}{3} = 556 \text{ kilowatts.}$$

Therefore the total kilowatts to be generated would be—

$$(4,428 + 556) = 4,984, \text{ say } 5,000,$$

and the combined efficiency $\left(\frac{2,905}{4,984}\right)$ would be 58·3 per cent.

This 5,000 kilowatts is the power required to be generated to work the 14 trains travelling 479 miles during the hour, as shown in Table IV., and upon it all comparative calculations and deductions have to be based.

The demand may, of course, go beyond this, or it may be less, but so long as the generating power, and that of the corresponding parts, is there to meet it, that branch of the question may be disregarded. As I have previously stated, the comparison is made between the ascertained quantities for doing a stated mileage at a stated speed. If the mileage were greater, or the number of trains greater, the comparison would be equally applicable. It is in respect of the mileage [illegible], so long as we apply it to a fairly representative condition. The speed and the train load indicated in Table [illegible], bearing in mind that the number of trains are regarded as all carrying the full load indicated, [illegible].

A generating plant capable of an output of 10,000 kilowatts is, of course, ample to provide for a calculated demand of less than that amount. I adopt the following estimate as [illegible]—

Generating Station.

[illegible]	£50,000	
[illegible]	200,000	
		£250,000

Sub-Stations.

[illegible]	10,000	
[illegible]	70,000	
		£80,000

Cables, including laying	£70,000	
Contact rail—200 miles (*i.e.*, 4 roads of 50 miles each)	70,000	
		140,000
Total capital outlay for generation and distribution of current		£470,000

The figures comprised within the two first items are practically those given by Mr. Parshall with reference to a somewhat similar plant, with the exception that the amounts have been increased to the extent of £15,000 for the generating station equipment, consequent upon the adoption of a higher voltage; and £10,000 for generating station buildings to meet any advance of prices. £10,000 has also been added for independent transformer buildings. The cost of cables, including laying in position, is based upon the current demand and mileage.

The hourly demand has been shown to be 5,000 kilowatts. The annual output for the section of line under consideration will therefore be this amount multiplied by the twenty-four hours per day, and 365 days to the year, viz., 43,800,000 kilowatt hours.

On this basis I estimate the annual cost for generation and distribution of current as shown in the annual column of the following table, from which, by dividing the sums there shown by the annual kilowatt output, I obtain the per kilowatt-hour charge.

To the foregoing we have to add the cost for drivers and assistants in attendance upon the electric locomotives—performing practically the same duties as the driver and firemen in attendance upon the steam locomotive; together with that for repair and renewal of all machinery, including the locomotives.

In his presidential address to the members of the Institute of Mechanical Engineers in 1898, Mr. S. W. Johnson, the Locomotive Engineer for the Midland Railway, furnished valuable data in relation to the cost of moving railway trains. From this data I, by his courtesy, am enabled to furnish the details shown on Table VI.

Mr. Chamen dynamos as with the engines which might not so well stand the extra speed.

He was sorry that Mr. Ionides had been alone in the defence of multiphase current supplies, and thought he ought to have been better supported. No doubt multiphase current could be utilised for driving variable speed motors to some extent, and also for electric furnaces, but there did not appear to be any particular advantage in the use of it, even for these purposes, and it must be remembered that the main question now under consideration was the general supply of electricity for lighting firstly, and then for any other purposes which might be made to fit in.

With regard to the question of costs it must be remembered that no fine economy had been possible in Glasgow for some time past, where the supply had to be carried on under conditions of great difficulty in works under construction.

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The Three Hundred and Fifty-Second Ordinary General Meeting of the Institution was held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, on Thursday evening, November 29th, 1900—Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on November 22nd, 1900, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that these names should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Thomas Ernest Herbert.

From the class of Students to that of Associates—

John Frank Auguste Margetts.

Messrs. J. H. Johnson and S. J. Clay were appointed scrutineers of the ballot for the election of new members.

A donation to the Library was announced as having been received since the last meeting from Société Anonyme John Cockerill, and to the *Building Fund* from Mr. James Kynoch, to whom the thanks of the meeting were duly accorded.

The PRESIDENT : I have to announce that on the 18th of December a Reception will be held at the Covent Garden Opera House, which has been most kindly lent for the

purpose by the Managers, Mr. Rendle and Mr. Forsyth. The Institution will then, assisted by the Corps of Electrical Engineers, Royal Engineers, Volunteers, receive the Active Service Contingent of that Corps on its return from South Africa. The 18th of December has been chosen because, although the return of the South African Detachment is, I believe, announced for the 8th or 9th of that month, there are delays in ships, and we felt it was well to have a safe date. Notices will be sent to members in the ordinary course.

I will now ask Mr. Langdon, Vice-President, to read his paper.

ON THE SUPERSESSION OF THE STEAM BY THE ELECTRIC LOCOMOTIVE.

By W. LANGDON, Vice-President.

Probably one of the most interesting questions associated with the application of electrical energy to railway work is its eventual supersession of the steam locomotive. Electric locomotives of a capacity equal to that of the steam locomotive, doing similar work, and possessing certain marked advantages, are an accomplished fact, and to many it may seem that the days of the steam locomotive are numbered. We must not, however, forget that that which has been done has its *raison d'être.* Its employment has hitherto been generally confined to localities where the effects of steam and smoke would exercise a baneful influence. Because it has been so employed, and its employment has been attended with such marked success, it does not follow, however much it may appear desirable, that in overland lines of railway electricity will in future prove to be the element of power. Railways are commercial undertakings, in which vast sums of money have been embarked, all of which, investors expect, will produce a certain annual return. The supersession of the steam by the electric locomotive thus resolves itself, primarily, into one of profit and loss. If its adoption will enable railways to be worked more economically than is the case under steam, then it will, with its attendant advantages, sooner or later, be adopted—if not by the whole, certainly by the greater portion of the railways of

this country; but, whatever the ulterior advantages may be, unattended by this result, its adoption will remain doubtful.

The first question to be asked is: Are we in a position to consider the subject? Is the data at our disposal such as to admit of a reasonable treatment of it? The primary factors are well known. We know how many pounds of steam we can obtain from a given quantity of coal. The efficiencies of prime movers and electrical generators, the loss in transmission, transformation, and distribution are all determinable. Any advantages yet to come must be looked for in the steam generator and in the simplification and consequent ultimate increase of efficiency in the electrical apparatus. In each, no doubt, the future will see production cheapened. Labour may advance, but competition will grow, and in the price of the manufactured article we may reasonably look to the future to produce some advantage.

Having then the material at hand, it is reasonable to conclude that the consideration of the subject can only be attended with good; for, if it should be shown that advantage is to be anticipated from such a change, it will help us to grasp that which has to be attempted, and perhaps to evolve from the data at our disposal the course most desirable to follow.

The railways of the United Kingdom comprised on the 31st of December, 1899,[1] the following mileage of line:—

Double Line or more	11,977
Single Line	9,723
Total mileage	21,700

The number of locomotives employed for working these railways was 20,461. The total number of vehicles of all descriptions was rendered as 752,930. The year's cost for locomotive power, including stationary engines, was £16,491,377. The number of miles travelled by trains was 396,241,265. Number of passengers—exclusive of season tickets—1,106,691,991. The tonnage of minerals, 296,611,190; and of general merchandise, 117,011,835.

In dealing with a question of this nature it seems

[1] Board of Trade Railway Returns, 1899.

desirable to produce these figures; but they are, in fact, except to afford some idea of the magnitude of the subject, of very little use. The length of the passenger journeys is not stated, nor are the journeys taken by season ticket holders included. To be of value the per passenger mileage, including of course the journeys made by season ticket holders, should be given. The same objection applies to the mineral and goods tonnage statement. It records the tonnage declared as placed upon the railway, but whether it is carried one mile or one hundred miles is not shown. In fact the returns, as rendered, aid the consideration of the subject very little; and I am sorry to say the information in the hands of the railway companies themselves carries us no further.

Under these circumstances, the establishment of a common basis upon which to consider the relative cost presents much difficulty. The only manner in which it can be approached is by averaging the data obtainable, or by examining the work of a particular section of line.

In Table I., I furnish extracts from the Board of Trade Returns for the year 1899, showing the mileage of line, cost of locomotive power, train mileage worked, &c., for England and Wales, Scotland and Ireland, together with certain deductions therefrom applicable to these results; as also similar data in reference to six of the most important English companies.

In considering the mileage of line quoted, it should be metioned that the figures do not disclose the *mileage of roads*. Over many sections of the several lines of railway there are more than two roads. Most main routes working out of London possess four, and even six roads, for a considerable distance; and the same applies to other busy portions of the chief railway systems.

The table indicated shows that the cost of locomotive power for the United Kingdom, including stationary engines for pumping and other purposes, works out at 9·988 pence per train mile. That the cost for England and Wales is 10·253; for Scotland 8·862; and for Ireland 8·104 pence. And that this cost varies with the several companies quoted as follows:—London and North-Western, 9·477 pence; London and South-Western, 9·844; Great Northern, 9·892; Great Western, 9·905; Midland, 10·218; and North-Eastern, 12·266—their average cost being 10·267.

TABLE I.

MILEAGE OF LINE, COST OF LOCOMOTIVE POWER, TRAIN MILEAGE, ETC.,

For Year Ending December 31, 1899.

(a)	Length of Line in Miles open on 31st December, 1899. Double or more.	Single.	Total. (b)	Cost of Locomotive Power, including Stationary Engines. (c)	No. of Locomotives. (d)	Number of Miles Travelled by Trains. By Passenger Trains. (e)	By Goods and Minerals. (f)	Total. (g)	(h) Cost per Train-mile for Locomotive Power. $\frac{c}{g}$	(k) Number of Miles Travelled by Trains per hour during year of 365 days. $\frac{g}{8,760}$	(l) Number of Trains per Mile per hour (365 days to the year.) $\frac{k}{b}$
				£					Pence.		
England and Wales	9,933	5,111	15,044	14,101,842	17,411	178,684,803	151,377,966	330,062,769	10·253	37,678	2·505
Scotland	1,423	2,057	3,480	1,811,552	2,241	27,588,633	21,473,089	49,061,722	8·862	5,601	1·609
Ireland	621	2,555	3,176	577,983	809	10,367,617	6,749,157	17,116,774	8·104	1,954	0·615
Total—United Kingdom...	11,977	9,723	21,700	16,401,377	20,461	216,641,053	179,600,212	396,241,265	9·988 Average.	45,233	2·084 Average.
	RAILWAY COMPANIES.										
				£					Pence.		
Great Northern			825	995,690	1,259	11,729,522	12,426,497	24,156,019	9·892	2,757	3·3
Great Western			2,602	1,884,032	1,933	23,085,687	22,561,470	45,647,157	9·905	5,210	2·0
London and North-Western			1,924	1,927,049	2,959	26,285,278	22,515,697	48,800,975	9·477	5,570	2·9
London and South-Western			900	709,110	728	12,598,390	4,689,644	17,288,034	9·844	1,973	2·2
Midland			1,431	2,016,816	2,507	18,979,594	28,387,090	47,366,684	10·218	5,407	3·7
North-Eastern			1,632	1,632,967	2,047	14,641,572	17,307,802	31,949,374	12·266	3,647	2·2
									Average 10·267		

Column *l* indicates the number of trains, per mile per hour, based upon the mileage of line of railway shown by the returns. Bearing in mind that there are, over many portions of the railways indicated, several lines, or roads, the number of trains travelling per mile per hour is, perhaps, surprisingly small. Ireland claims but 0·615; Scotland, 1·609; England and Wales, 2·505. Of the railways individualised, the Great Western has an average of but 2; the London and South-Western and the North-Eastern each 2·2; London and North-Western, 2·9; Great Northern, 3·3; and the Midland, 3·7 (that is, the Midland, for instance, has, on an average, 3·7 trains passing over each *mile of line of railway*, each hour; not that the mile of line is occupied by these 3·7 trains during the entire hour, but that that is the average number of trains worked over the mile of line of railway—quite irrespective of the number of lines of rails—within that period of time).

If trains were, in practice, so distributed, this might form a basis on which to found a comparison of cost for the entire railway system; but we know that this is not so—that trains are much more frequent on certain portions and less frequent on other portions of the lines of railway, and although it is a kind of basis, affording some very interesting figures, it is not, as it stands, a practical one for the purpose in view. To effect this it is necessary to consider the work of an individual section of some line of railway; and with this view I have taken that portion of the Midland Company's main line between London (St. Pancras) and Bedford —omitting the suburban and local traffic applicable to the Metropolitan and Tottenham lines.

The length of line of railway is 49·5 miles—practically 50 miles; and the number of lines of rails applicable to the traffic under consideration may be taken as four—it is not less. In order to ascertain the number and character of trains to be taken into consideration, I have obtained returns (Tables II. and III.) extracted from the Block Book, of those trains passing two points—Luton and Harpenden—each hour, during a day of twenty-four hours in the month of July, 1900, which I have summarised and classified so as to bring the subject within reasonable scope. These details are carried forward to Table IV., which forms the basis of

calculation for comparison of cost for power to work the traffic indicated.

Table II.

LUTON.

Statement of the Number of Trains recorded in the Block Book for the 24 hours ending midnight on Thursday, July 19, 1900.

Hours.	Express Passenger.	Ordinary Passenger.	Coaches.	Fish and Milk.	Express Goods. Class "A."	Express Goods. Class "B."	Ordinary Goods.	Minerals.	Light Engines.	Total number of Trains each hour.
12 to 1 a.m. ...	2	—	—	—	1	5	—	3	—	11
1 " 2 " ...	—	—	1	—	—	10	—	2	—	13
2 " 3 " ...	—	—	1	3	1	3	—	5	—	13
3 " 4 " ...	1	—	—	—	—	3	—	6	—	10
4 " 5 " ...	1	—	—	—	3	5	—	6	—	15
5 " 6 " ...	2	—	—	—	2	4	1	2	—	11
6 " 7 " ...	1	1	—	—	3	—	1	5	—	11
7 " 8 " ...	1	1	4	—	2	4	1	3	—	16
8 " 9 " ...	1	1	—	—	1	2	—	2	—	7
9 " 10 " ...	4	—	—	—	—	2	—	4	—	10
10 " 11 " ...	4	1	—	—	—	1	1	4	—	11
11 " 12 (noon) ...	3	—	—	—	1	1	1	3	—	9
12 " 1 p.m. ...	4	1	—	—	—	1	2	5	—	13
1 " 2 " ...	4	1	1	—	—	2	—	4	—	12
2 " 3 " ...	6	2	3	—	—	—	—	8	—	19
3 " 4 " ...	2	3	—	—	1	—	3	5	—	14
4 " 5 " ...	4	—	1	—	—	—	1	5	—	11
5 " 6 " ...	4	2	—	—	—	—	2	3	—	11
6 " 7 " ...	5	1	—	—	—	—	—	4	—	10
7 " 8 " ...	4	2	1	—	—	—	—	5	—	12
8 " 9 " ...	—	2	1	—	3	—	—	1	—	7
9 " 10 " ...	2	—	—	—	1	2	—	4	—	9
10 " 11 " ...	5	2	—	—	—	—	2	7	—	16
11 " 12 (midnight)	2	1	2	—	1	6	3	1	—	16

Classification.

Express Passenger...			62
Ordinary Passenger		21	36
Coaches		15	
Fish and Milk		3	74
Express Goods—Class "A."	20	71	
" Class "B."	51		
Ordinary Goods		18	115
Minerals		97	
Total number of Trains during the 24 hours ...			287
Maximum number of Trains in 1 hour			19
Minimum " " "			7

TABLE III.

HARPENDEN.

Statement of the Number of Trains recorded in the Block Book for the 24 hours ending midnight on Thursday, July 19, 1900.

Hours.	Express Passenger.	Ordinary Passenger.	Coaches.	Fish and Milk.	Express Goods. Class "A."	Express Goods. Class "B."	Ordinary Goods.	Minerals.	Light Engines.	Total number of Trains each hour.
12 to 1 a.m. ...	2	—	—	—	3	3	1	4	—	13
1 " 2 " ...	—	—	1	—	—	9	2	2	—	14
2 " 3 " ...	—	—	1	3	1	3	2	1	—	11
3 " 4 " ...	—	—	—	—	2	3	3	3	—	11
4 " 5 " ...	1	—	—	—	2	5	4	1	—	13
5 " 6 " ...	3	1	—	—	2	4	2	1	1	14
6 " 7 " ...	—	—	—	—	—	2	5	1	1	9
7 " 8 " ...	2	3	2	—	2	5	—	—	1	15
8 " 9 " ...	4	1	—	—	1	—	5	3	—	14
9 " 10 " ...	5	2	—	—	—	1	3	1	—	12
10 " 11 " ...	3	1	—	—	1	1	—	1	—	7
11 " 12 (noon) ...	5	—	—	—	—	2	2	2	—	11
12 " 1 p.m. ...	5	2	1	—	—	1	1	2	—	12
1 " 2 " ...	3	2	—	—	—	1	6	3	1	16
2 " 3 " ...	5	3	1	—	—	1	3	2	1	16
3 " 4 " ...	4	1	1	—	—	1	2	3	1	13
4 " 5 " ...	3	5	—	—	—	—	2	2	—	12
5 " 6 " ...	5	1	—	—	—	—	2	2	—	10
6 " 7 " ...	3	1	—	—	—	—	2	2	1	9
7 " 8 " ...	6	2	—	—	2	—	1	—	—	11
8 " 9 " ...	2	3	—	—	1	2	1	3	1	13
9 " 10 " ...	3	2	—	—	—	3	3	3	1	15
10 " 11 " ...	3	2	—	1	1	1	1	2	1	12
11 " 12 (midnight)	—	1	1	—	4	4	2	2	—	14

CLASSIFICATION.

Express Passenger ...			67
Ordinary Passenger ...		33	41
Coaches ...		8	
Fish and Milk ...		4	78
Express Goods—Class "A." ...	22	74	
" " Class "B." ...	52		
Ordinary Goods ...		55	111
Minerals ...		46	
Light Engines ...		10	
Total number of Trains during the 24 hours ...			297
Maximum number of Trains in 1 hour...			16
Minimum " " " ...			7

TABLE IV.

BASIS OF CALCULATION.

Showing Number of Trains, classified, passing certain points of a 50-mile Section of Line of Railway; calculated Mechanical Horse-power and Electrical power for working the same, together with apportioned speed, load, etc.

Class of Train.	No. of Trains per Day of 24 hours passing.		Basis of Calculation.							Total.	
	Luton.	Harpenden.	Apportioned No. of Trains per hour.	Speed. Miles per hour.	Train Miles per hour.	Load, including Engine. Tons.	Total Tractive Effort per Train. lbs.*	Mechanical H.P. per Train.	Equivalent in K.W. hours.	Mechanical H.P. per hour.	Equivalent in K.W. per hour.
1. Express Passenger	62	67	3	50	150	275	3,575	477	356	1,431	1,068
2. Ordinary Passenger and Empty Coaches	36	41	2	32	64	300	2,130	182	136	364	272
3. Express Goods and Perishables	74	78	4	35	140	400	3,160	295	220	1,180	880
4. Ordinary Goods and Minerals	115	111	5	25	125	500	2,750	183	137	915	685
Totals	287	297	14		479					3,890	2,905
Average per hour	11·9	12·4									

Tractive effort, lbs., per ton $= 3 + \frac{V^2}{250}$ where V = speed in miles per hour. * Tractive effort × load tons = Total tractive effort per train.

$$\text{H.P.} = \frac{\text{Tractive effort lbs.} \times \text{miles per hour.}}{375}$$

The classification adopted is necessarily somewhat arbitrary, but in its construction I have endeavoured to err on

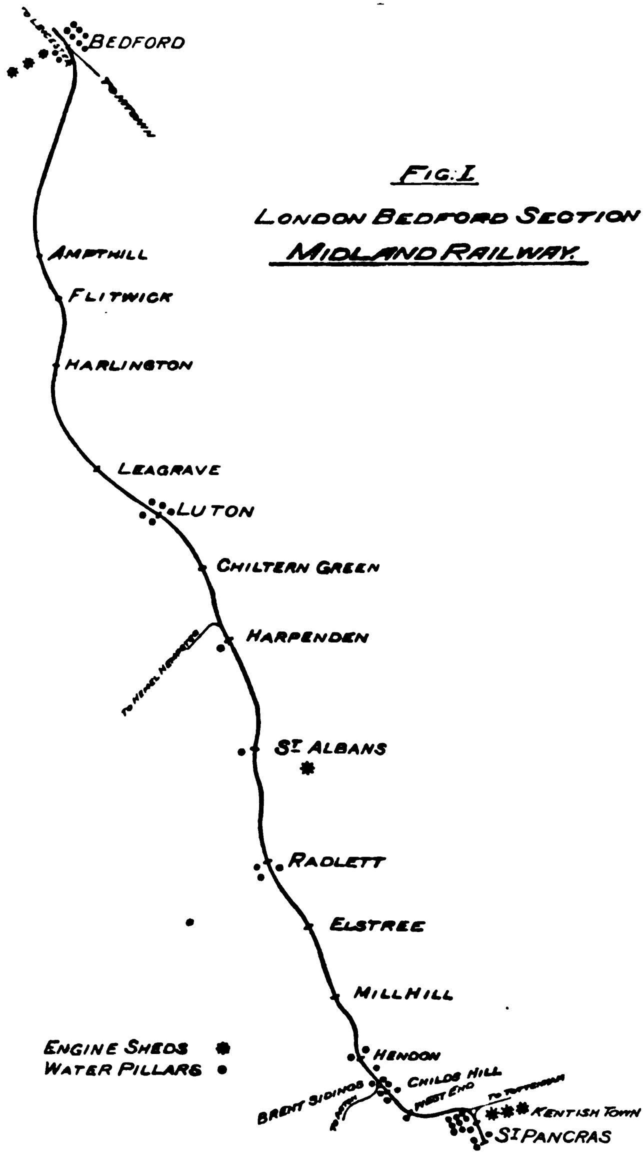


FIG. I
LONDON BEDFORD SECTION
MIDLAND RAILWAY.

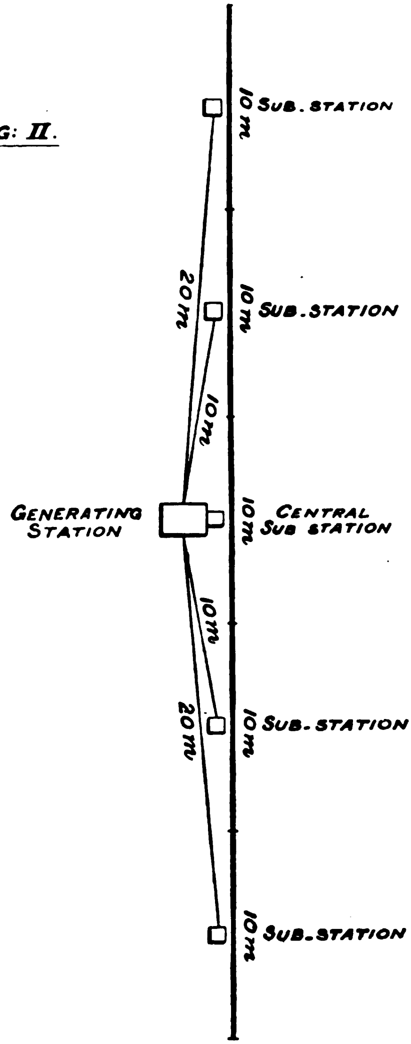
the right side—for instance I have debited each train of its class as a loaded train, whereas some would certainly be

light trains. Again I have, I believe, accorded to each their full merit of speed, although there is reason to assume that, in many instances, certain goods and minerals would not observe that allotted to them. From this table we get the tractive effort per train, and the consequent mechanical and electrical power required to deal with *one hour's work.* The work may, and of course does, vary from one hour to another; indeed, that is clearly shown by Tables II. and III.; for instance, the trains passing Harpenden vary per hour from 7 to 16, and Luton from 7 to 19, but the section of line chosen may be regarded as a full line, a line well occupied by trains both night and day, Sundays and week-days. The returns show an average of 11·9 trains passing Luton and of 12·4 passing Harpenden, per hour. In taking an average, however, I have apportioned no less than 14 trains to the hour. This number divided between the four lines of metals gives a result of 3·5 trains per mile per hour, per line of metals. It may here, however, be as well to point out that, so long as the appropriated number of trains is fairly that in practice, the number applied is, for comparison purposes, immaterial, for the comparison I draw is based upon the train mileage cost.

Fig. 1 illustrates the section of line under consideration. The position of engine-sheds is shown by stars (*); of water-cranes by dots (•). The short or suburban traffic between St. Pancras and Hendon, and the Tottenham line, &c., is not included in my schedules, for the reason that, viewing the section of line as if actually subject to electrical working, there would be little doubt that this immediate London-Suburban traffic would demand a generating station nearer home than that indicated in the scheme I have adopted as my basis for the comparison of costs for working a 50-mile section of line.

The Plant scheme is roughly outlined in Fig. 2. Midway in the 50 miles of railway is the central station, containing four 2,500 kilowatt, three-phase, or other characteristic, 10,000 volt generators. At this pressure current is distributed to substations, each serving 10 miles of railway, where the potential is converted to 600, from whence it is carried to the contact-rail. Or the centre 10-mile section may be provided for by direct-current generators served from the same steam plant.

FIG: II.



The efficiencies of the various parts are assumed as follows :—

	Loss. Per cent.		Efficiency.
Motors	15	...	·85
Ohmic loss in rails ...	10	...	·90
Leakage	$2\frac{1}{2}$	...	·975
Rotary converters ...	10	...	·90
Static transformers ...	7	...	·93
H.T. transmission ...	10	...	·90

The total kilowatts required on the train-wheels (Table IV.) is 2,905 per hour, and the number of trains is 14. Therefore $\left(\frac{2{,}905}{14}\right)$ 207·5 will be the average kilowatts per train hour; and, assuming the efficiency of the motors at 85 per cent., $\left(\frac{207{\cdot}5}{{\cdot}85}\right)$ 244 kilowatts will be the average power required to be supplied to each train. If now we allow 10 per cent. loss in the rails which supply and return the current, a pressure of 540 only will be available at either end of a section of 10 miles. Therefore the amperes per train that will be required will be $\left(\frac{244 \times 1{,}000}{540}\right)$ 452.

As there are 14 trains per hour in the total 50 miles section, there will be $\frac{14}{5} = 2{\cdot}8$, say 3 trains in one section of 10 miles to be supplied by one substation.

$$452 \times 3 = 1{,}356 \text{ amperes.}$$

Adding $2\frac{1}{2}$ per cent. for leakage, we have 1,390 amperes as the current to be supplied by each substation at 600 volts.

The efficiency of the converters and static transformers is taken at, respectively, 90 per cent. and 93 per cent., and the three-phase transmission at 90 per cent.

$\therefore \frac{1{,}390 \times 600}{1{,}000 \times {\cdot}9 \times {\cdot}93 \times {\cdot}9} = 1{,}107$ k.w. to be delivered to the trains for each section containing 3 trains.

As there are 14 trains, there will be 4 sections with 3 each, and 1 section with 2 trains.

Now the 4 sections with 3 trains each would require—

$$1{,}107 \times 4 = 4{,}428 \text{ kilowatts.}$$

To allow for the maximum loss let it be assumed that the centre 10-mile section, which as previously indicated might be supplied direct at 600 volts, is so dealt with, and that it is the section that has two trains only.

The kilowatts required would equal—

$$\frac{1{,}390 \times 600}{1{,}000} \times \frac{2}{3} = 556 \text{ kilowatts.}$$

Therefore the total kilowatts to be generated would be—

$$(4{,}428 + 556) = 4{,}984, \text{ say } 5{,}000,$$

and the combined efficiency $\left(\frac{2{,}905}{4{,}984}\right)$ would be 58·3 per cent.

This 5,000 kilowatts is the power required to be generated to work the 14 trains travelling 479 miles during the hour, as shown in Table IV., and upon it all comparative calculations and deductions have to be based.

The demand may, of course, go beyond this, or it may be less, but so long as the generating power, and that of the corresponding parts, is there to meet it, that branch of the question may be disregarded. As I have previously stated, the comparison is made between the ascertained quantities travelling a stated mileage at a stated speed. If the mileage were greater, or the number of trains greater, the comparison would be equally applicable. It is, in respect of the mileage result, immaterial, so long as we apply it to a fairly representative condition. The speed and the train load indicated in Table IV. will, I believe, bearing in mind that the number of trains are regarded as all carrying the full load indicated, be found to conform to this.

A generating plant capable of an output of 10,000 kilowatts is, of course, ample to provide for a calculated demand of just half that amount. I adopt the following estimate as applicable to the prime cost :—

Generating Station.

Buildings, foundations, chimney stacks, &c.	£50,000	
Equipment, including steam units, boilers, coal conveyers, steam mains, condensers, pumps, &c.	200,000	
		£250,000

Substations.

Buildings—5 stations	10,000	
Equipment of ditto with transformers, converters, &c., delivering at 600 volts, and all necessary fittings ...	70,000	
		£80,000

Cables, including laying	£70,000	
Contact rail—200 miles (*i.e.*, 4 roads of 50 miles each)	70,000	
		140,000
Total capital outlay for generation and distribution of current		£470,000

The figures comprised within the two first items are practically those given by Mr. Parshall with reference to a somewhat similar plant, with the exception that the amounts have been increased to the extent of £15,000 for the generating station equipment, consequent upon the adoption of a higher voltage; and £10,000 for generating station buildings to meet any advance of prices. £10,000 has also been added for independent transformer buildings. The cost of cables, including laying in position, is based upon the current demand and mileage.

The hourly demand has been shown to be 5,000 kilowatts. The annual output for the section of line under consideration will therefore be this amount multiplied by the twenty-four hours per day, and 365 days to the year, viz., 43,800,000 kilowatt hours.

On this basis I estimate the annual cost for generation and distribution of current as shown in the annual column of the following table, from which, by dividing the sums there shown by the annual kilowatt output, I obtain the per kilowatt-hour charge.

To the foregoing we have to add the cost for drivers and assistants in attendance upon the electric locomotives—performing practically the same duties as the driver and firemen in attendance upon the steam locomotive; together with that for repair and renewal of all machinery, including the locomotives.

In his presidential address to the members of the Institute of Mechanical Engineers in 1898, Mr. S. W. Johnson, the Locomotive Engineer for the Midland Railway, furnished valuable data in relation to the cost of moving railway trains. From this data I, by his courtesy, am enabled to furnish the details shown on Table VI.

TABLE V.

ESTIMATED COST OF GENERATION AND DISTRIBUTION OF CURRENT.

[Output, 43,800,000 kilowatt hours.]

Details of Charges.		Per Annum. £	Per Kilowatt hour. Pence.
1. Capital outlay, £470,000. Interest at 3½ per cent.		16,450	0·0901
2. *Generating Station.*			
Salaries and Wages :—	£		
1 Chief Engineer	500		
1 Assistant ditto	250		
3 Switchroom attendants, at £150 each	450		
1 Clerk	120		
7 Engine-room attendants, at 40s. each per week... ...	728		
7 Assistant ditto, at 35s. each per week	637		
12 Stokers, at 30s. each per week	936		
15 Labourers and Cleaners, at 22s. each per week ...	858		
		4,479	0·0245
Coal.			
At 3·0 lbs. of coal per kilowatt hour—58·660 tons, at 7s. 11½d. per ton ...		23,345	0·1279
Water.			
At 25 lbs. per kilowatt hour, and 2d. per 1,000 gallons		913	0·0050
		28,737	0·1574
3. *Substations* (5).			
Salaries and Wages :—	£		
5 Assistant Engineers, at £200 each	1,000		
20 Attendants, at 40s. each per week	2,080		
20 Assistant ditto, at 35s. each per week	1,820		
10 Cleaners, at 22s. each per week	572		
		5,472	0·0299
4. *Outdoor Service.*	£		
5 Rail-jointers and Fitters at 40s. each per week	520		
Material, &c.	230		
		750	0·0041
5. Oil, Waste, and Sundries		2,000	0·0109
Total estimated cost of Generation and Distribution of Current		£36,959	0·2023

TABLE VI.

STEAM LOCOMOTIVE CHARGES.

Average Midland Railway Total Annual Locomotive Expenditure, &c., during 24 years, 1873-96.		Cost per Train Mile.
Running Expenditure.	£	Pence.
Wages :—Drivers and Firemen	358,635	2·650
Cleaners, Coal men, &c.	94,422	0·698
Water	28,575	0·211
Oil and Stores	44,842	0·331
Coal and Coke	289,595	2·139
Total Running Expenditure	£816,069	6·029
Repairs and Renewals.		
Wages	178,718	1·320
Materials...	178,742	1·321
Total Repairs and Renewals	£357,460	2·641
Salaries	24,187	0·179
Turntables and Buildings	2,861	0·021
Gas	9,868	0·073
Gross Expenditure	£1,222,899	8·943

Tons of Coal and Coke consumed	727,889
Cost per Ton	7s. 11½d.
Train Mileage	32,485,530

This table shows that the average cost for twenty-four years, for drivers and firemen was £358,635, or 2·650 pence per train mile; and that for repairs and renewals, £357,460, or 2·641 pence per train mile.

To arrive at the cost for drivers and attendants for the electrical locomotive, I might revert to Table IV. and deduce from it, at a given rate of wage per hour, for the number of trains occupying the line for that period, the kilowatt-hour cost, but this, it appears to me, would not be quite right. There can be no question that the cost incurred by the locomotive department is extremely heavy,[1] but it is a

[1] Assuming the weekly wage of driver and fireman to amount to ninety shillings, probably an excessive sum, it would seem that the weekly mileage travelled would be but 407. If the wage were seventy shillings, the mileage would be but 317.

charge incumbent upon the working of the traffic, and whatever are the conditions which militate against a reduction in this charge with the locomotive department, presumably they would hold good against the electric unless the traffic could, under the latter, be so facilitated as to enable it to be got through with greater speed, and less shunting. It is not clear this could be done. I am therefore, very reluctantly I must admit, obliged to adopt the extremely heavy cost incurred by the steam locomotive, for there would be very little, if any, difference in the rate of pay to the respective class of men.

The repair and renewal of electrical machinery, whether in relation to the generating or the locomotive plant, should be considerably less than that of the steam locomotive plant, for the reason that there will be extremely few moving parts, while many small units, used for pumping and other like purposes, would be provided for from the central generating station at a less cost, or entirely abolished.

The train mileage (Table IV.), run by the fourteen trains during one hour, is 479. Assuming that the cost attending the repair and renewal of the electrical machinery will be 2d. per train mile, as against that for the steam locomotive power and works, viz., 2·641, we shall have a result of 0·1916 pence per kilowatt hour.

There is yet one more addition to make. The cables and contact-rail are peculiar to the electrical system. I do not include them in the above 2d. per train mile for repair and renewal of machinery. Having regard to the value of the recovered material, I assume 2½ per cent. on the primary outlay will meet the renewal of cables, and 4 per cent. that of the contact-rail. This means 0·0249 pence per kilowatt hour.

Table VII. furnishes all these items, against each of which is also shown the cost per train mile, *i.e.*, the cost per kilowatt hour multiplied by the total output, viz., 5,000 kilowatts for the hour's work, divided by the train mileage worked during the hour, viz., 479.

TABLE VII.

ELECTRICAL CHARGES.

Cost in Pence, per Kilowatt Hour, and per Train Mile.

	Per Kilowatt Hour.	Per Train Mile.
Generating charges	0·1574	1·643
Sub-stations charges	0·0299	0·312
Out-door attendance	0·0041	0·043
Oil, waste, and sundries	0·0109	0·114
Locomotive drivers and assistants. [This item is shown at the cost incurred under present mode of working] -	0·2538	2·650
Repair and renewal of machinery, motors, &c. ...	0·1916	2·000
Renewal of cables and contact-rail	0·0249	0·259
Total cost for power and haulage	0·6726	7·021
Interest at 3½ per cent. on primary outlay, viz., £470,000	0·0901	0·941

Therefore, if my deductions are correct, it would appear that the cost of working by electricity as against that for the steam locomotive is, per train-mile, so far as the Midland is concerned, as 7·021 to 8·943 pence, being an apparent saving of 1·922 pence per train-mile, or £260,155 on the average yearly cost for the 24 years indicated.

A closer comparison of the chief items may help us to learn where and how so large a saving is effected.

Coal stands in Mr. Johnson's data at 727,889 tons, at a cost of £289,595. Based upon the figure adopted by me, viz., 3·0 lbs. per kilowatt hour, the tonnage required is 454,145,[1] and the money £180,712.[2] The steam loco-

[1] $\frac{5{,}000 \text{ K.W.} \times 3·0}{479} = 31·315 \quad \frac{32{,}485{,}530 \times 31·315}{2{,}240} = 454{,}145$ tons.

[2] $\frac{·1279^{d} \times 5{,}000 \text{ K.W.}}{479} = 1·335073^{d}$ per T.M.

$32{,}485{,}530.$ T.M. $\times\ 1·335^{d} = £180{,}712.$

motive consumes on the average 50·191 lbs. of coal per train mile. My figures place the quantity required for electrical energy at $\frac{(5,000 \times 3\cdot0)}{479}$ 31·315 lbs. The saving under this head is, therefore, 273,744 tons, which at 7s. 11½d. will account for £108,927. We have to bear in mind that the calculation on which the cost of electricity is based makes no provision for shunting operations. It is based entirely upon the train mileage run. Shunting work is, of course, included in Mr. Johnson's figures, and will account, to some extent, for the difference. The main gain, however, is to be found in the economy of a stationary, as against an itinerant generator, as well as in the fact that much coal is consumed by goods and mineral trains when shunted, and by all trains when standing at stations, the whole of which would be saved if worked by electricity.

With stationary engines a less expensive coal than that used for locomotives would be available, thereby effecting a reduction probably more than sufficient to meet the cost for shunting previously alluded to. It may be pointed out that coal is more costly at present. Such is the case, and, were my calculations based upon the present rate of coal, the result would largely enhance the advantage of electricity. Say, for instance, that coal stood at 10s. instead of 7s. 11½d., the locomotive cost would be 727,889 tons at 10s. = £363,944 instead of £289,595. That for electricity would be 454,145 tons at 10s. = £227,072, instead of £180,701. The result would be that electricity would show, under coal at 10s. a ton, a saving of £136,872 instead of £108,927, on precisely the same mileage, with a proportionate increased saving at prices ranging above that figure.

The fact that dear coal enhances the comparative value of an electrical system—especially with the possibility of coal at a higher rate than 7s. 11½d.—cannot be too strongly emphasised.

Water.—The steam locomotive calls for £28,573, or 0·211 pence per train mile; electricity, £7,066, or ·0522 per train mile—a difference in favour of the latter of £11,507. It is difficult to attempt a comparison between the cost of a largely-scattered supply—water pillars at numerous stations—and a concentrated one—one to every 50 miles or so of line. The site for such a generating station would naturally be

selected with a view to cheap water supply, and, as a rule, no great difficulty would attend its selection. A further point to be borne in mind is that, naturally, all machinery would be of the most modern and economical type, and that the working would reach the highest ideal for an electrical plant, viz., an actually constant and perpetual demand.

Drivers.—It is quite clear that whatever may be the cause of the existing heavy charges, it will apply equally to electric as to steam locomotives. The engine must stand by its train, and the men along with it. Any reduction that may be effected will be in the mode of dealing with the traffic. The present condition, viz., that of a mixed traffic travelling at various rates of speed—one class of train being required to make room for another of a more important character—is not destined to effect economy in this branch of expense.

Repair and Renewal.—I have assumed that the cost of repair and renewal would be practically $\frac{1}{3}$th less with electricity than steam. I think I am more than justified in this. The wear and tear of stationary engines, or motors, cannot possibly be so great as that of the steam locomotive. The number of electric locomotives would necessarily be as great, but their wearing parts would be immensely less, than those of the latter. Many local units would be entirely dispensed with.

Oil and Stores forms a somewhat large item in the running expenses of the steam locomotive. Much of this is for the lubrication of moving parts which would be non-existent in electric engines. Moreover, with stationary engines it is possible to recover, and again use, a great portion of the lubricator employed. It would appear that considerable economies in oil should accompany the employment of electricity.

We may now perhaps glance at possible economies on that which is indispensable for the steam locomotive, but which is unnecessary, or not so largely necessary, with electricity. Water pillars, turntables, engine sheds, coal stages—all these are expensive items which with electricity are either not required, or capable of considerable modification.

Water pillars, supplemented in many instances by fixed engine-power for pumping the water into reserve tanks, involving power-houses, sheds, and other structures, form part of all large stations and many other points at which the locomotive requires to take water. With electricity, water to any extent would be required only at that point at which the central generating station is placed. If this station served fifty miles of railway, then it would take the place of all the pumping plants, water pillars, &c., otherwise required throughout that section for the steam locomotive. Every pumping station involves the provision of labour, fuel, &c. All water pillars require special attention during hard weather. Economies in first outlay and annual charges on this account should accompany the use of electricity.

Turntables would be unnecessary. The annual outlay for repairs in this respect is not great, but the cost of laying down the large turntables now required is very heavy.

As the number of locomotives increase, so increases the demand for engine sheds. Electric locomotives would of course need housing as well as the steam locomotive, but the space which they would occupy would probably be about half that now required.

Wherever we find an engine shed, there we see an area of land covered with coal; lines of rails applicable thereto; coal-stages to which the coal has to be carried, and from which it has to be distributed to the locomotives. First the coal has to be stacked, then loaded into trucks and carried to the coal-stage; and thence weighed and placed on the engine's tender. This is the course of procedure at each engine depôt. If we compare it with the work of a large central station, such as that sketched out in this paper, I think it will come home to us that although the work would be large, it could not be nearly so large as at present. If stacking were at all necessary there would be the less quantity to stack, and it would all be dealt with in a more concrete form and at comparatively few centres. Again, in this respect there is reason to look for economies in land, in buildings, and labour.

All these are assets directly due to the employment of electricity. Others, not considered in the figures which I have advanced, would, with its presence, be available: the lighting of the trains, stations, goods warehouses and yards,

marshalling grounds, &c. Signalling, to some extent, might become automatic; while at large centres where signal boxes have become both numerous and cumbrous, it would appear but reasonable that, with the aid of such a power, points and signals might not only be actuated, but the means for operating them might be so condensed as to admit of the entire duties being embraced within such a space as would enable one man to deal with them. Labour and space would be economised, and less time would be occupied in giving effect to the various operations than is possible with the existing means. To this we may add that obviously it would also provide for the operation of lifts, and other local demands for power which at present have to be met by isolated plants.

Let us now turn to what may perhaps be regarded as difficulties to be encountered.

The first question that will arise will be :—Are we safe in placing so many of our eggs in one basket? With the steam locomotive we have a travelling unit which has to manipulate its own load and is in no way responsible for the duties of others. If it breaks down, the inconvenience is chiefly confined to the vehicles it is hauling, and in due course they are extricated from their difficulty by the aid of another engine.

With electricity we are locating our power at one spot in so many miles of line, and if that breaks down that section of line is practically dead. But with the usual spare parts —the duplication, if necessary, of the generating units— there should be no reason to anticipate such a failure. The same argument in a measure applies to the power at the distributing stations. Here, however, the case may be met not only by duplication, but by, in emergency, connecting one section through to its neighbour. For the time being inconvenience would be felt; speed would be reduced, but traffic would not be stopped. Of all this we have evidence in that which has already been done. We see railways being worked, tramways operated, and other large undertakings all dependent upon one large and central source for their life and being. Electric railways have become an accomplished fact, and we may turn to those that are in use as exponents of success or of difficulties to be encountered.

Does the magnitude of the question we are considering—the eventual supersession of the steam by the electric locomotive—remove it from the category of that which has so far been done? I think not. The basis is there. It is to-day in useful operation. Improvements will come. The mode of working which we see to-day may, and probably will, be simplified, but this will only strengthen that which has already been accomplished.

Still, there are points of great interest for consideration. As a rule, that which has been done has, with one or two exceptions, been confined to underground lines, and these exceptions have not as a rule dealt with such heavy work as the large overland railways require to compass. Overground railways have to work through all kinds of weather—rain, snow, fog—and at times to pass over rails submerged in water. Winter floods are not unusual in certain localities of nearly all overland railways. These are conditions which will affect the construction of the locomotive, the arrangement of the current collector, and the contact-rail, and are subjects for thought not only in themselves but in relation to the mass of under-gear which now appertains to all passenger railway stock, as also to the relative position and construction of roads, their repair and renewal.

A question may here intervene whether a similar economy would attend the operation of small branch lines of railway where the trains are few and far between. Consider! Why are the trains so few and far between? The traffic is, we will say, a fixed quantity. There are only so many tons of goods and so many passengers passing over it daily. The steam locomotive is available only at certain times, and to attain economy it is necessary that so many trips only should be made. The accommodation is limited to this. But if the power for working the trains were constant, although reduced, any number of trips might be made. The additional cost would be that only of the driver, for the rest the branch would be no more costly, while the frequency of the communication would tend towards the development of the district, and the consequent increase of trade.

I have now, I believe, fairly set forth the salient features of this question. The data which I have produced speaks greatly in favour of electrical energy as a motive power for the movement of railway trains. The economies which it would apparently effect are, indeed, so large as to raise a doubt whether my deductions—whether the figures I have adopted—are fair and reasonable. It must not be forgotten that my calculations are based upon a mileage run clear of stoppages or other contingencies. Stoppages are unavoidable. They *will* arise, and provision must be made to meet them. But I find it difficult to identify them further than I have already done. Stoppages will not affect the coal bill. I have taken the present cost of drivers and firemen to apply to that for drivers and assistants for electric locomotives. My allowance for repair and renewal of machinery will, I think, be generally supported. Necessarily the subject has to some extent had to be dealt with more in the abstract than in detail, but I venture to hope my figures will not be found illiberal. We must not lose sight of the fact that the conditions are a constant load and continuous output for every hour of the year. I believe the cost of shunting at stations and in goods yards may be met by the economy attending the use of a cheaper coal than that which is necessary for the steam locomotive; but assuming that some provision should be made for this, for administration and contingencies, I conclude that 20 per cent. (say £50,000) of the accredited saving will cover it.

We thus bring the net annual advantage to approximately £208,124, and if we deduct interest on the primary outlay it will further reduce it to £191,674. Whether it is, in face of the savings to be affected in engine-sheds, coal-stages, water-cranes, &c., fair to make a debit in full of this amount, I must leave those who are interested in the question to determine. Broadly, it appears to me to mean this: that were a new company to start with electricity as their motive-power, they would not need to take into consideration the interest on the entire additional outlay, because they would save a great portion of it in other directions.

But were an established company to adopt it, they would already have incurred the cost for the lands, buildings, &c., and the expense for establishing electric working would

unavoidably prove to them, for some years, an addition to their capital charges.

Although I feel that my reason for pursuing such a course will be obvious, it may be desirable that I should emphasise the fact that my sole object in availing myself of the data afforded by Mr. Johnson's presidential address to the members of the Institution of Mechanical Engineers is that I might deal with data extending over a long period of years, rather than draw a comparison with a period which might be regarded as possessing some abnormal feature. It must, however, be noted that recent figures tend to greatly magnify the result. I have shown that, with electrical working, certain economies are to be anticipated. The annual amount of these economies is based upon the ascertained saving *per train mile*, multiplied by the average annual mileage for the twenty-four years—viz., 32,485,580. The mileage for 1899 is 45,453,438, and the expenditure £2,006,069, as against the twenty-four years' average £1,122,899; and the train-mile cost has risen to 10·59 as against 8·943 pence. Assuming that the saving per train mile remained the same—it would probably be larger, consequent upon the increased cost of coal—the resultant saving would be, independent of any deductions for interest or contingencies, £364,006.

Large as is the apparent economy thus presented, it would, were it possible to employ a gas plant for so large an output, be increased by the use of the "Mond" gas system. Such a system would appear to invite consideration, at all events, for smaller installations, as, for instance, for the operation of branch lines.

Here it may perhaps be asked: What good can attend the production of these figures, or the results they advocate, seeing that the railway system generally is wedded to the steam locomotive? Is it probable that any railway company will cast on one side their present equipment for the purpose of taking up that, which, although holding out fair hopes of a large economy, is yet, in a measure, or in the large measure to which it would have to be applied, mainly an untried agent? To this I reply: Railway companies are under the direction of business men—men who know the value of money. Satisfy them that economies are to be effected—and do not let us forget that the economies are

not confined solely to those with which this paper has dealt, but probably to many others indirectly associated therewith—and that the economy embraces a reliable means of working, and they will not be found undesirous of testing its worth. The life of a steam locomotive is not an indefinite quantity. Its replacement by one of more modern construction or of greater power, quite apart from its ultimate destruction by wear and tear, is an appreciable fact. As traffic increases, so additions have to be made. We see so many new engines ordered year by year. What is to prevent a railway company, instead of thus perpetuating its annual costs, setting apart portion by portion of their system for operation by electrical energy, and, instead of ordering for, say, that portion of their system, steam, to order electric locomotives; and thus to bring, piece by piece, their entire system under electrical operation? No sane railway management would do otherwise; and I assume that, should my figures stand unrefuted, no railway company would desire to follow any other course. Prove its economy, prove its reliability, and there is nothing in the fact that railways are, for the time being, the slave of the steam locomotive, to militate against their supersession by electrical energy.

That this paper deals with a problem which, sooner or later, will force itself upon the attention of all who are interested in railway progress, few will be disposed to dispute. So far it has been considered solely in the realm of economical working—in the interest of the railway shareholder. But are we justified in looking at it only from this standpoint? Does it not embrace a question of still greater magnitude? Is it not one of even national interest? If, by the aid of electricity, we can save no less than 18·876 lbs. of coal per train mile, it is clear we could save *no less than three million tons* a year [1] if all our railways were worked by that agency.

View it again from still another standpoint. Twenty thousand locomotives moving about throughout the land cannot fail to leave their mark behind them. Our railway

[1] 396,241,265 train miles × 18·876 lb. = 3,339,040 tons.

stations, the telegraphs which traverse the railway routes, the trees which grow on its borders, all bear evidence of their presence.

The supersession of the steam locomotive by the electric locomotive will bring with it a purer and a more cleanly atmosphere—cleanly railway stations—cleanly railway carriages—a higher and a purer sanitary condition of life.

Mr. Robinson.

Mr. MARK ROBINSON: I am sure I shall not be accused of wasting the time of the meeting in compliments if I begin by expressing the view, which I believe all present hold, that this is a most interesting and valuable paper. It deals with a matter of the utmost importance to the country and to its industries. It is one we are all anxious to hear about, and it has been put before us in the most practical manner, by dealing with a concrete case. Mr. Langdon's conclusions, even if we think some deductions should be made from them, cannot fail to be welcome to many in this room. He has not spoken as an enthusiast—scarcely as an advocate—and he has treated the subject with complete impartiality and moderation. In fact his almost excessive moderation is my excuse for attempting to criticise him, and for endeavouring to show that he has not made the best case for electricity which the circumstances, as given in his paper, admit of. Mr. Langdon proposes five sub-stations, each feeding ten miles of line, with a continuous current of 600 volts. I have no wish, and do not propose, to question his scheme in these leading features: I only hope to show that, these being granted and his estimates assumed correct, a different arrangement of plant would lead to a great reduction in first cost as well as in working expenses. If his estimates are too high or too low, that does not affect my argument, which relates only to comparative results, and might be based equally well upon any other figures. What I question is the need for the big central station which supplies the sub-stations, for I believe that 2,000 kilowatts could be generated in each of the five stations as economically as 10,000 kilowatts could be generated in one large central station, or if not as economically, then so nearly as economically that there would still be great advantage in working by the more numerous and smaller stations. The 10,000 kilowatts correspond to about 16,000 horse-power, or say four engines of 4,000 H.P. each. It is commonly believed that as engines attain to very large sizes they become much more economical, and it is probably Mr. Langdon's view that there will be such notable savings in coal and in other things as to justify the great cost of the cables leading to the sub-stations and the very serious losses which he foresees in transformation. I venture to assert that there is no such great economy in increasing the size of the engines. It is reasonable to suppose that Mr. Langdon has turned for inspiration to the country where electric traction has received its greatest development, namely, America, where they believe very much in large stations. But in America only the slow-running engine is present to the minds of their engineers, and of such engines it is true

that economy improves with increase of size. It ought to do so, because the relation between the exposed surface in the cylinders (which is the immediate cause of condensation, the principal heat loss we have to guard against) and the volume of steam which the cylinders contain becomes more favourable as the size of the cylinder increases. Really high-speed engines, which are chiefly used in this country and are practically unknown elsewhere, stand, however, upon quite a different footing. In them a new factor tending to economy comes into play, which has practically no existence in any slow-running engine, namely, the great shortening of the period during which the surfaces are exposed to the successive alternations of temperature. That is undoubtedly the chief reason for the remarkable economy of the English fast-running engines even down to very small sizes. In such engines, when you decrease the size, you are able still further to increase the speed and to further reduce the time of exposure of the surfaces, so as to more or less completely compensate for the increased condensation due to the worse ratio between the surfaces and the volume of the cylinder. In a slow-running engine the speed may also be increased as the size diminishes, but within far smaller limits, and the speed attainable with this type of engine, however small the engine may be, is in no case sufficient to act materially upon economy. These facts, though apparently ignored out of this country, are established by trials and records well known to the scientific world, and I would apologise for bringing them forward in discussing a subject apparently remote from the merits of rival types of engines, if it were not that the capacity of one type, and of one type only, to give very economical results in moderate sizes goes really to the root of the question. Those who remember the remarkable figures obtained in the well-known experiments of the late Mr. Willans, may have forgotten that the engine on which he tried those experiments, and with which he obtained a consumption of only 12½ lbs. of steam per indicated horse-power, was of 40 H.P. only. On the score, therefore, of steam economy there is no necessity to use very large engines, or to collect all the power in one great station; hence the main (high-tension) cables may be left out, and a great loss of energy, as well as first cost, avoided. To go to figures, I would first say that I have consulted several electrical engineers who have had experience of stations large and small, and they support my belief that stations of about 3,000 H.P. (the size of Mr. Langdon's substations) can be run at almost, if not quite, the same cost per kilowatt as a station very much larger. Each of the five stations would be a little smaller than I could wish; possibly four would give a better result, but even the suggested stations of 2,000 kilowatts each would contain three engines of 1,000 H.P. each, or four of 750, and I venture to say either of these would use as little steam per kilowatt as engines of any size or type. They would certainly cost less for attendance, and the office management expenses would in my opinion be no greater. Five such stations on the same line of railway, and connected by telephone, would be practically one concern, each separate station being merely a foreman's job. The several stations would assist each

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Mr. Robinson.

other with current, and I should not anticipate any excessive changes of load in the separate stations as the trains passed from one section to another. Only this week I have been engaged in designing a station which is to have some 10,000 H.P. in it, and it was actually found desirable for convenience, and for safety against breakdowns, to divide this large power into groups of plant, of course in the same engine-room. If those groups stood ten miles apart (all on sidings on the same railway) I do not think the inconvenience would be great. Assume that in each of the ten-mile sections a site can be found with good water supply, which perhaps is a large assumption, and that we install one-fifth of the power there, and that all the stations, instead of one only, deliver continuous current direct to the rails. Let us assume that the five stations cost as much to build as the one big one (priced at £50,000 in the table on page 136), plus the £10,000 which has been allowed for the five sub-stations; they will then cost £60,000. I think that is a safe estimate, because very large stations increase rapidly in cost, owing to the great height of the buildings, the large span of the roofs, and the great power and weight of the travellers required. Assuming also that the £200,000 provided for generating plant is available and is sufficient, as I believe it would be, for the five smaller stations, then we should at least save the £70,000 allowed for the equipment of the sub-stations, for the transformers, and so on, and we should further save the £70,000 put down for cables. That is £140,000 out of £470,000, and it brings our first cost down to £330,000. But in addition we should wholly save the 17 per cent. which is given us, at page 134, as the loss of energy in the rotary converters and the static transformers, and we further save the 10 per cent. lost in the high-tension transmission. Hence the 1,107 kilowatts required (page 135) to be delivered to each section containing three trains, is reduced to 834 kilowatts, and the total is reduced from 4,984 to 3,892 kilowatts, a reduction of no less than 22 per cent., involving also a reduction of 22 per cent. off the £260,000 we have allowed for the buildings and plant. This amounts to over £57,000, so that we really bring down this £470,000 capital charge to about £273,000, and we may hope to save the same 22 per cent. upon the cost of running the plant. I am prepared to learn that there may be difficulties in finding five sites for stations conveniently placed on these five sections, with good water supply, so that either from a reduction in the number of stations or from some being disadvantageously placed, something would have to be given back again in the form of increased cost for conductors; but the total saving at our disposal is really so great that we can afford to deduct a good deal from it and yet show a very large gain. On railways with a very light traffic spread over a long distance, or on Metropolitan lines where there would be a difficulty in getting sites for stations, high-tension transmission with transformers at the end may be perfectly right, but for railways in general that system ought to be the exception rather than the rule. There is another economy which Mr. Langdon, I am glad to see, has in reserve, namely, that when a railway becomes wholly electrical the passenger trains may be run upon the better system of having the motors on the axles of the carriages, which for passenger trains gives many advantages, and is

less hard upon the permanent way. I can only thank Mr. Langdon again for having given us such a very fruitful paper, and a paper which should set us all thinking. Mr. Robinson.

Mr. G. C. CUNNINGHAM: The extremely interesting and valuable paper that Mr. Langdon has read opens up, I think, a very fruitful subject for discussion. The question of the application of electricity to locomotion, to my mind, largely turns upon the question of the pounds of coal per ton mile. Some years ago I wrote a short paper, that was published in the Proceedings of the Institution of Civil Engineers, upon the subject of the consumption of fuel in locomotive engines on railways. That was at a time when I was in Canada as chief engineer of the Canada Southern Railway. This railway line is extremely level, with very flat gradients—there are none more than fifteen feet to the mile—and it is almost entirely free from curves. There is one long straight section of fifty-three miles, joined by another long straight portion of fifty-four miles. Hence this line was perhaps the very best possible for doing work with a small consumption of fuel. The goods trains on that line were therefore long, and were drawn by one engine. The consumption of fuel by these goods trains worked out at 0·15 of a pound of coal per ton mile. On the passenger trains, where a much higher speed was obtained, the consumption of coal was 0·8 of a pound per ton mile. Now, of course, electrical railways present precisely the same problem, the gradients of the line affecting the amount of power used. The quantity of power is dependent upon the resistance of the line—that is mainly on the gradients of the line. On the Liverpool Overhead Railway, which is practically a level line, I found in a paper, which was read before the Institution of Civil Engineers some few years ago, that the quantity of coal burnt per ton mile was 0·4 of a pound. On the Central London Railway, of which we have had a brief experience—I hope you have all had experience of it—the quantity of coal, irrespective of that which is consumed for station lighting and lifts, per ton mile consumed in the power-house, covering all losses in transmission and transformation and so forth, is 0·5 of a pound, as near as I can get it at present, per ton mile. Of course this is, as I say, dependent upon the amount of power used, and the amount of power is again a question of gradient. In Mr. Langdon's very interesting paper the question of power seems to have been assumed at some standard amount, irrespective of the gradients. The quantity of power used on such a line as the Central London, irrespective of the lighting and lifts, is something like 70 watt-hours per ton mile. But, as showing how very much this power varies with the gradients, I may say that on the Montreal Electric Railway, a line running through the streets, of which railway I was the general manager for some years, the quantity of power used was something like 300 watt-hours per ton mile. There, of course, the gradients were very severe, in some cases as steep as 1 in 10 up steep streets. It is therefore difficult *a priori*, until we know the character of a railway, to say how much power would be used on it. Of course, the cost of producing the power again depends upon the character of the power-house in which it is produced. In my own experience the lowest consumption of coal that I have known in pro- Mr. Cunningham.

Mr. Cunningham. ducing a kilowatt-hour is 3·6 pounds, and the lowest cost (*i.e.*, shop-cost) that I have known is something slightly over a farthing, irrespective of depreciation or interest on capital. But that I conceive is a low cost, and I do not know of any case in which it has been further reduced. The question of the application of electricity to railways is one, the development of which would be watched with very great interest by all those associated with electrical work. But I think it is a question that depends almost entirely on the construction of economical power-houses and the economical distribution of the electrical current.

Mr. Parsons. Mr. C. A. PARSONS: I think we are very much indebted to Mr. Langdon for bringing forward this most interesting and important subject at the present time. I may say that it seems to me that the subject has been treated on a thorough and systematic basis, and that the figures he has placed before us (as far as I can judge) err, if anything, on the liberal side. The case might, I think, have been made out more favourable to the electrical running of trains, but Mr. Langdon has thought it wiser to allow a considerable margin. In the cost of generation of electricity, for instance, I think his figure of 3 lbs. of coal per kilowatt-hour errs on the liberal side, in view of the large scale of the generating plant. The question of generating from one central station rather than from a number of small stations connected by telephone, to which Mr. Robinson has alluded, is, I think, scarcely the point before the meeting this evening, but is more of the nature of a side issue. The broad and important question is rather whether trains can in general be propelled electrically on a large scale at anything like the cost of the steam locomotive; and this, I think, has been conclusively shown to be the case by Mr. Langdon. It further seems to me that when the electrical system is worked out in practice there will manifest themselves many and unexpected economies which at the present time cannot be realised. The one great advantage of the large central stations and of high-tension, long-distance transmission, is, of course, the liberty which it affords to the designers of placing the stations in situations where there is practically free water in unlimited amount for condensing and also easy access for coal, and suitable places for the artisans to live. There is no doubt, from the experience I have had, that the larger the station the cheaper it can be run, in consequence of the greater developments in organisation, management, and machinery which are economically possible in an undertaking of the greater magnitude. I think we are very much indebted to Mr. Langdon, and I may, perhaps, repeat that I consider the paper one of the utmost value and importance, and that it may assist towards the initiation of large developments in the application of electricity to the driving of trains.

Mr. Hoy. Mr. H. A. HOY: I have not had time to prepare many notes on Mr. Langdon's interesting paper, but I may say at once that I do not propose questioning any figures which the author has collected from Mr. Johnson's very able paper read before the Institution of Mechanical Engineers. I think locomotive men are practically unanimous with regard to any question that may arise out of those figures, but the little

study which I have given to the question of electric traction on railways leads me to fall in with the views which have been expressed by Mr. Mark Robinson with regard to the use of a direct current at say 600 volts being fed to the main line in sections, and by smaller units than has been suggested by Mr. Langdon in his paper. I fail to see why any resort should be made to the use of large power-stations at infrequent intervals, entailing the use of static and rotary transformers, although the efficiency of those transformers is as high as it can be hoped to expect of them. As Mr. Langdon points out, the loss of efficiency is very small, especially with the static transformers; yet to this must be added the loss of efficiency in one or more rotary transformers, which by reason of them being so made are necessarily less efficient. I suggest that the whole of this be saved by serving sections of railway with direct current from generating stations of a capacity suitable for the work to be done. Most of the members are aware of what Colonel Heft has done upon the New York, New Haven, and Hartford Railway of America. No attempt has been made there to introduce anything beyond what I have named, and the information that I obtained on the ground was to the effect that any extension would follow on the same lines. I believe if a current was fed in the way indicated, a greater efficiency would result than that which is suggested in the paper. One reason lies in the fact that by relying upon large central stations at infrequent intervals there is not so much scope for taking advantage of suitable sites for obtaining water for condensing purposes, which is a very important point, as indicated by Mr. Parsons. The position of the central station as shown in Mr. Langdon's paper, viz., at Harpenden, about twenty-five miles from London, is not, so far as my knowledge of the geography of that part of the country extends, a suitable place for obtaining a large continuous supply of water for condensing purposes. It has occurred to me, and I think it relates to the question under discussion, that something further might be done than was suggested by Mr. Mark Robinson—something on the lines of our friends in America, but not quite so much as has been done with the Heilman locomotive in France—namely, to have moving generating stations in which the current is produced upon a vehicle and charged direct into the third rail, such a vehicle to be provided with a motor of only sufficient power to move itself at a moderate pace. Suitable engines of a high-speed type and generators would be provided, and the whole would form an electric locomotive not necessarily to be used for tractive purposes excepting in the way I have indicated. The advantages, from a railway traffic manager's point of view, would be very great, because such moving electrical plants could be distributed where the greatest power is required, and thus get rid of one disadvantage at least, viz., that of a fall of voltage due to generators being so far away from their work. Mr. Hoy.

Mr. J. S. RAWORTH: We have the pleasure of seeing Mr. Langdon once more amongst us reading a paper. I want to say one word about Mr. Langdon's paper, and to call attention to the thanks that we owe him for the industry and perseverance with which he puts these papers before us. Mr. Raworth.

Mr. Cunningham. ducing a kilowatt-hour is 3·6 pounds, and the lowest cost (*i.e.*, shop-cost) that I have known is something slightly over a farthing, irrespective of depreciation or interest on capital. But that I conceive is a low cost, and I do not know of any case in which it has been further reduced. The question of the application of electricity to railways is one, the development of which would be watched with very great interest by all those associated with electrical work. But I think it is a question that depends almost entirely on the construction of economical power-houses and the economical distribution of the electrical current.

Mr. Parsons. Mr. C. A. PARSONS: I think we are very much indebted to Mr. Langdon for bringing forward this most interesting and important subject at the present time. I may say that it seems to me that the subject has been treated on a thorough and systematic basis, and that the figures he has placed before us (as far as I can judge) err, if anything, on the liberal side. The case might, I think, have been made out more favourable to the electrical running of trains, but Mr. Langdon has thought it wiser to allow a considerable margin. In the cost of generation of electricity, for instance, I think his figure of 3 lbs. of coal per kilowatt-hour errs on the liberal side, in view of the large scale of the generating plant. The question of generating from one central station rather than from a number of small stations connected by telephone, to which Mr. Robinson has alluded, is, I think, scarcely the point before the meeting this evening, but is more of the nature of a side issue. The broad and important question is rather whether trains can in general be propelled electrically on a large scale at anything like the cost of the steam locomotive; and this, I think, has been conclusively shown to be the case by Mr. Langdon. It further seems to me that when the electrical system is worked out in practice there will manifest themselves many and unexpected economies which at the present time cannot be realised. The one great advantage of the large central stations and of high-tension, long-distance transmission, is, of course, the liberty which it affords to the designers of placing the stations in situations where there is practically free water in unlimited amount for condensing and also easy access for coal, and suitable places for the artisans to live. There is no doubt, from the experience I have had, that the larger the station the cheaper it can be run, in consequence of the greater developments in organisation, management, and machinery which are economically possible in an undertaking of the greater magnitude. I think we are very much indebted to Mr. Langdon, and I may, perhaps, repeat that I consider the paper one of the utmost value and importance, and that it may assist towards the initiation of large developments in the application of electricity to the driving of trains.

Mr. Hoy. Mr. H. A. HOY: I have not had time to prepare many notes on Mr. Langdon's interesting paper, but I may say at once that I do not propose questioning any figures which the author has collected from Mr. Johnson's very able paper read before the Institution of Mechanical Engineers. I think locomotive men are practically unanimous with regard to any question that may arise out of those figures, but the little

study which I have given to the question of electric traction on railways leads me to fall in with the views which have been expressed by Mr. Mark Robinson with regard to the use of a direct current at say 600 volts being fed to the main line in sections, and by smaller units than has been suggested by Mr. Langdon in his paper. I fail to see why any resort should be made to the use of large power-stations at infrequent intervals, entailing the use of static and rotary transformers, although the efficiency of those transformers is as high as it can be hoped to expect of them. As Mr. Langdon points out, the loss of efficiency is very small, especially with the static transformers; yet to this must be added the loss of efficiency in one or more rotary transformers, which by reason of them being so made are necessarily less efficient. I suggest that the whole of this be saved by serving sections of railway with direct current from generating stations of a capacity suitable for the work to be done. Most of the members are aware of what Colonel Heft has done upon the New York, New Haven, and Hartford Railway of America. No attempt has been made there to introduce anything beyond what I have named, and the information that I obtained on the ground was to the effect that any extension would follow on the same lines. I believe if a current was fed in the way indicated, a greater efficiency would result than that which is suggested in the paper. One reason lies in the fact that by relying upon large central stations at infrequent intervals there is not so much scope for taking advantage of suitable sites for obtaining water for condensing purposes, which is a very important point, as indicated by Mr. Parsons. The position of the central station as shown in Mr. Langdon's paper, viz., at Harpenden, about twenty-five miles from London, is not, so far as my knowledge of the geography of that part of the country extends, a suitable place for obtaining a large continuous supply of water for condensing purposes. It has occurred to me, and I think it relates to the question under discussion, that something further might be done than was suggested by Mr. Mark Robinson—something on the lines of our friends in America, but not quite so much as has been done with the Heilman locomotive in France—namely, to have moving generating stations in which the current is produced upon a vehicle and charged direct into the third rail, such a vehicle to be provided with a motor of only sufficient power to move itself at a moderate pace. Suitable engines of a high-speed type and generators would be provided, and the whole would form an electric locomotive not necessarily to be used for tractive purposes excepting in the way I have indicated. The advantages, from a railway traffic manager's point of view, would be very great, because such moving electrical plants could be distributed where the greatest power is required, and thus get rid of one disadvantage at least, viz., that of a fall of voltage due to generators being so far away from their work. Mr. Hoy.

Mr. J. S. RAWORTH: We have the pleasure of seeing Mr. Langdon once more amongst us reading a paper. I want to say one word about Mr. Langdon's paper, and to call attention to the thanks that we owe him for the industry and perseverance with which he puts these papers before us. Mr. Raworth.

*Mr. Raworth.

I have followed Mr. Langdon's figures pretty closely, and mine do not come out quite the same as his, but it will be better if criticisms come from our side rather than the other. The President has very properly called on the locomotive superintendents present to come forward, and I have been wanting the man to come forward who would say that Mr. Langdon is all wrong, and that his suggestions could not be carried out, for we would at once refute his arguments. I have looked over Mr. Langdon's figures, and on Table II. he says that the maximum number of trains per hour passing through Luton is sixteen, but in the column on the right-hand side you will find there are nineteen. Then you find in Table III. that ten trains more go through Harpenden per day than through Luton, but they are, curiously enough, all light engines. I do not know whether Mr. Langdon will be able to give us an explanation of the fact. When we come to a calculation of the power required to drag trains from London to Bedford, I am sorry to say I have not been able to follow Mr. Langdon quite clearly through his calculations. He has adopted a nomenclature of his own, and though I have succeeded in mastering it to some extent, I thought it better to recalculate the whole from the beginning. On Mr. Langdon's figures I took out the total foot-pounds that would be required to drag the 287 trains over the fifty miles in twenty-four hours, and then I have divided that out and brought out the total result at 7,380 kilowatts, with an average of twelve trains per hour. Then providing for a possible maximum of sixteen trains per hour, not nineteen, and allowing 600 kilowatts for acceleration, with four stops on the average in the distance, I find that the total kilowatts required is 9,850, which shows that Mr. Langdon, after all, is not such a bad guesser in fixing the power of the station at 10,000 kilowatts. I do not think we shall grumble at Mr. Langdon because he has allowed a fair margin that will cover any method of calculating the results, because it must be clearly understood that results cannot be found out exactly; they must, in every case, be subject to a certain amount of guess work. For nstance, Mr. Langdon's formula of the tractive power per ton is $3 + \frac{V^2}{250}$ miles per hour. Although I am not now a railway man, I was once, and I think there must be some little error in the formula of Mr. Langdon's, because you will observe that if we only went one mile an hour we should have no more force to push the train than 3 lbs. per ton.

Mr. Langdon.

Mr. LANGDON: I should have mentioned that the formula is not applicable under five miles an hour.

Mr. Raworth.

Mr. RAWORTH: I give in at once. There are one or two points in Mr. Langdon's calculations in which, I think, he has in his usual kind manner given the benefit to the steam locomotive. In the first place he has taken the expenses for the last twenty-four years of the steam locomotive, and he has taken expenses for the present year with the electric means of propulsion. You will readily imagine that this is very much in favour of the steam locomotive. I think a few years ago the locomotive took from 29 to 30 lbs. of coal per ton-mile; now it takes from 50 to 51 lbs. A few years ago wages were very much lower than they

are now. We have to pay on the higher scale, whereas the calculation is made upon the lower scale. Mr. Raworth.

Mr. H. A. MAVOR: We are all very much indebted to Mr. Langdon for bringing this paper before the Institution. What I wish to say is that, if agreeable to the Council of the Institution, we of the Glasgow section would like the discussion kept over until after the 12th of December, so that we may arrange to have a full discussion of the paper to be embodied in the Transactions of the Institution. We have in the north a large number of very highly skilled locomotive engineers who are able to discuss the question, and we hope that our contribution to the discussion will be worth recording. Under these circumstances I will not take up more time in discussing the question now. Mr. Mavor.

Colonel R. E. CROMPTON: I am, unfortunately, not prepared to do justice to this most interesting paper, as I intended to speak during the adjourned discussion, but an engagement prevents me from doing so. I must, therefore, confine myself to a few words this evening. Colonel Crompton.

This is a case where the importance of the matter calls for the very best opinions of the electrical world, and I hope that these will be given very freely during the discussion.

I am particularly appreciative of this paper, as I have designed an electrical railway 160 miles long worked from three stations approximately 40 miles apart. This is a Trans-Himalayan line, and to be worked by water-power. In the course of studying the project, it was necessary to prepare data very similar to those given in Mr. Langdon's Table IV. If I had had that table before me it would have greatly facilitated my labours. It happens that I did prepare my time-table of trains on lines very similar to those followed by Mr. Langdon. One of the first points which I have noticed is the extraordinary discrepancy between the horse-power taken by the trains, as calculated for in column 4, and the actual horse-power of the locomotives when working to their maximum efficiency; in fact this descrepancy at once excited the interest of us electrical engineers, who have so long been accustomed to talk about the load-factor of our steam engines, and the effect that it has on their economical efficiency. It is evident that the comparatively small load-factor of a steam locomotive working an ordinary railway is most probably one of the causes why the locomotive which, taken as a whole, *i.e.*, boiler and engine together, ought to be an economical machine, is not in practice found to be really economical. This small load-factor also explains why the introduction of compound steam locomotives has been so delayed, and its economical advantages are even now disputed by some locomotive engineers.

Mr. Langdon shows, and it is evidently the case, that the substitution of fixed stations, from each of which the power required for several trains would be supplied, must be a means of improving the load-factor of the generating plant which supplies that section of the line.

Turning to another point, that of the wages, which Mr. Langdon shows is a very important item in the cost of working steam locomotives. I do not think he is quite fair to the electric locomotive when he debits it with the same wages as the steam locomotive. No doubt he is wise in thinking that at first there would be no great saving on

Colonel Crompton.

this head, and that if the directors of an electric railway attempted to economise in this direction the public would be alarmed, and would imagine that unskilled men were employed. But I wish to point out that the drivers of steam locomotives are exceptional men and have to be paid an exceptionally high rate of wages, because they are not only men of great nerve and judgment, as regards the mere driving of their trains, observing signals, and other matters which affect the safety of the travelling public, but they have to combine with this a highly skilled training in the management of the locomotive as a power-producing machine. I refer, of course, to the best methods of working the steam, times of firing the boiler, and other things necessary to get the highest duty out of the boiler and steam engine. Now the driver of the electric locomotive need only be skilled in the first part of these duties, and this fact alone ought to reduce the rate of wages paid.

I will touch on another point, and that is the question of repairs of the locomotive machinery. I think these will be far lighter in the case of the electric than can ever be the case with a steam locomotive. For instance, the points at which wear takes place to the greatest extent, and which cost most to repair and keep in order, are the sliding surfaces exposed to the weather, dust, mud, rain, etc.; these sliding surfaces, such as those of the piston-rods, guide-bars and links of the steam locomotive, are absent in the electric locomotive. The friction surfaces of the electric locomotives are confined to journals, and these can be far more easily protected from the weather than the sliding surfaces. Again, the locomotive boiler, excellent though it be, costs far more money to maintain than the stationary boiler of the electric system. Again, I think that the substitution of driving by a large number of axles on the train will greatly reduce the weight on these driving-wheels necessary to obtain adhesion, and this will very greatly reduce the cost of renewal of the permanent way.

While on this matter, I must point out that Mr. Langdon has not made a point for the electric system which he might have made. I think there are signs that in the future our steam locomotives will be overloaded, *i.e.*, they cannot be made big enough and powerful enough to haul the traffic at the required speed; they are limited by the gauge, position of platforms, bridges, etc. Already in some cases the diameter of the driving-wheels must be reduced in order to get in overhanging boilers, so that some modern locomotives are becoming like camels (at least, I think that this is what locomotive engineers are calling them).

Again, they are limited in length by the existing turn-tables. All these are signs that the steam locomotive power has reached its limit, and it is only by distributing our motive power over a considerable proportion of the train itself that we can increase the driving power and hence the speed. I think this is a strong argument in favour of the introduction of the electric system.

The Chairman.

The CHAIRMAN announced that the scrutineers reported the following candidates to have been duly elected :—

Members:

Herbert Broadbent. | John Somerville Highfield.

Associate Members:

James Anderson. | Arthur Woodroffe Manton.
Marcus Nash.

Foreign Member:

Otto Peder Krogh.

Associates:

Harry Watkins Kimber. | Arthur Henry Pook.
Thomas Mills. | David Shanks.

Students:

William Beale Cole. | John Marshall.
Ernest Ferdinand Motta.

The Three Hundred and Fifty-Third Ordinary General Meeting of the Institution was held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, on Thursday evening, December 6th, 1900, Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on November 29th, 1900, were read and confirmed.

Donations to the Building Fund were announced as having been received since the last meeting from Mr. A. T. Snell and Mr. T. Mills, to whom the thanks of the meeting were duly accorded.

Messrs. H. L. Leach and W. H. Merriman were appointed scrutineers of the ballot for new members.

RESUMPTION OF DISCUSSION ON PAPER BY MR. W. LANGDON, VICE-PRESIDENT, ON THE "SUPERSESSION OF THE STEAM BY THE ELECTRIC LOCOMOTIVE."

Mr. Hammond.

Mr. ROBERT HAMMOND: I think we must all be struck in reading this most valuable paper of Mr. Langdon's at the immense new field which he is opening out for the young as well as the old electrical engineers. One cannot help, when viewing this vast field, being reminded of the great achievements that our modest force of electricity has made in the past. All must have enjoyed the speech made by Sir William Preece in the discussion on Mr. Gavey's paper, when he pointed out that more than twenty-five years ago the Institution marvelled over the great discoveries that were being made in the application of electricity to the telegraph, and how every new invention succeeded, by the utilisation of the wires then in existence, in very greatly enlarging the power of the electric telegraph. I was not a member of this Institution in those days, but I can quite accept Sir William Preece's account. It is, however, within my memory, and within that of many in the room, that our members generally were astonished to know that electricity was going to compete for lighting with the great gas industry. When the bold conception was started that we should be able to distribute electricity from a centre and use it for lighting our houses, those of us who were pioneering that movement were much scoffed at. Well, the *Journal of Gas Lighting* notwithstanding, we have lived through that period, until we are beginning to consider that it is a matter of astonishment that there is still a gas light in existence. Then some few said, "If we can distribute energy for doing away with gas lighting, why not distribute it for the utilisation of our factories?" and last year we have seen the first great step that has been made in the passing of those

Mr. Hammond.

important power Bills. It is now within the power of some very eminent financiers in different parts of the country to show the faith that is in them and to distribute power from a centre for utilisation in great factories; and if all the anticipations of those various groups of financiers are realised, electricity will come in touch with every industry in the land. Then, finally we have Mr. Langdon in a most painstaking and valuable paper pointing out to us that there is still another field for the electrical engineer, namely, the supersession of the steam locomotive. There have been some very bold conceptions put forth at meetings of this Institution; but to me, as a constant railway traveller, there hardly seems a happier suggestion than that we should do away with the period when we ride behind a chimney and get so uncomfortable and covered with dust and dirt, just in the same way as we formerly were content to be illuminated at night with a light that was competing with us for the oxygen which is necessary for life. Mr. Langdon comes before us with a paper that does not deal in generalities. We are all indebted to Mr. Langdon for the paper, because he not only shows that such a thing is in his opinion possible, but he also shows from beginning to end how such a thing can be carried out. He does not hesitate to suggest certain methods of generation and distribution of electrical energy. He sets out the capital outlay which his scheme will cost. He deals with an actual fifty miles of line. He goes into the question of how he would place his sub-stations, his primary and his secondary voltage, and he works out the capital cost. That seems to me a very practical way of dealing with a paper of this kind. Finally he compares those costs with the costs that are, and have been for so many years, duly recorded by the steam railways, and he shows that on the average cost of a large number of years he is prepared to show a saving of over a quarter of a million. In taking the average cost over a great many years he has taken a figure which is really unfavourable to his argument, because it is well known among railway men that costs have tended to increase. Mr. Raworth, in a particularly happy speech at our last meeting, deprecated a criticism of the details of Mr. Langdon's scheme, and begged us to confine ourselves to the financial aspect. Of course it is manifest to us that, as far as the actual directors or railway shareholders are concerned, they care little about the methods, and they will adopt this new plan or not accordingly as it will increase or make more certain their dividends. But I cannot follow Mr. Raworth in his suggestion that the proper way of dealing with Mr. Langdon's paper is to deal with it only as a question of principle. He has laid before us a certain scheme. Mr. Mark Robinson, for instance, in opening the debate, ventured to point out that in his opinion, instead of have one central station, economy might be obtained by having some five central stations; and I think it would be the best compliment we could pay to Mr. Langdon, and would lead to the most practical outcome of this debate, if we discuss the details of this paper somewhat instead of confining ourselves to the general principle. The two main points of Mr. Langdon's paper which we, as engineers, should consider may easily be summed up. The first is, Is the plan of running full-gauge railways by electricity feasible? and secondly, Are the estimates that he lays before

Mr. Hammond. us in connection with this scheme sound or not? First, with regard to the feasibility. I think we may unhesitatingly let it go forth as the opinion of this Institution that that plan is feasible. I think we have sufficient data before us to say unhesitatingly that full-gauge railways can be run by electricity, and we are encouraged to say that because it is actually being done at the present moment. For the past eighteen months a line has been running, as many members know, from Burgdorf to Thun—a full-gauge line which was formerly worked by steam locomotives, and is now being worked by electric locomotives. That line has a length of about 25 miles. Comparing it with the plan laid before us by Mr. Langdon, I may recall the fact that the primary voltage there is 4,000 volts, and the secondary voltage is 750. It is 4,000 volts at the generating station, raised up to 16,000, and then it is lowered down to 750 on the 3-phase system. In addition to that line, there is another very much larger line. A line is being put down by the Shuckert Company and Ganz Company of Buda-Pesth for about 70 miles, and it will, when it reaches Milan, be 110 miles long. On the Burgdorf-Thun line the sub-stations are placed at distances of two miles apart, whereas on the Northern Italian line they are at distances of 10 miles. There the extraordinary plan is being introduced of running with a primary voltage of 20,000, and reducing it only to 3,000 on the motors on the car. When I was in Buda-Pesth a short time ago, I had the pleasure, in company with Mr. Blathy, of running over the trial portion of the line. They have laid down an actual track and are running cars upon that line, where the primary voltage is 20,000 and the secondary voltage in the car is 3,000.

With regard to the figures, I have gone very carefully through them, and I consider the estimates of working costs are sound. I consider that the points thrown down by Mr. Robinson are worthy of consideration. We must remember that the two lines I have referred to go from a central station, because at the central station there is water. Our problem in England differs from the problem in almost every part of the world in that we have coal apparently at 7s. 11½d. per ton, which can be easily taken to the point where it can be best used.

The President. The PRESIDENT: Before calling on Professor Forbes, I will ask the Secretary to read a letter received from Mr. Hoy, the locomotive superintendent of the Lancashire and Yorkshire Railway, who spoke last week.

Mr. Hoy. Mr. H. A. HOY (*communicated*): I should have liked an opportunity to point out to Mr. Langdon a misconception on his part which occurs on page 142, in which he says: "The main gain, however, is to be found in the economy of a stationary, as against an itinerant generator, as well as in the fact that much coal is consumed by goods and mineral trains when shunted, and by all trains when standing at stations, the whole of which would be saved if worked by electricity."

I beg to say that this is not so; in fact, very much the reverse. Mr. Langdon's stationary engine would be continually revolving, and coal will be consumed to produce these revolutions, although it may not be doing any legitimate work. On the other hand, with a locomotive the moment it comes to a stand the wheels cease to revolve,

and the consumption of fuel in the firebox is a negligible quantity, and the conditions of economy are more favourable than those which take place in the domestic fire-grate. An engine driver who knows his business, when he is put into a siding or when he stops for any length of time, closes his damper and opens the firehole door, thus preventing all draught from passing through the grate, a course of treatment which, if continued, would result in the fire going out altogether. Mr. Hoy.

The amount of power derived from the coal consumed in a locomotive firebox of limited area is so great that the fire is most sensitive to the fluctuations of load, hence the economy; whereas in the case of fuel being burnt in large stationary boilers, the effect upon the fire when the load on the stationary engine alters from maximum to minimum at intervals is not noticeable. Again, for the same reason, due to this elasticity of generative power, a large amount of coal is consumed in getting up steam and a proportionately large amount of fuel wasted if the load unexpectedly goes off for a considerable period.

Professor G. FORBES: I have very little to say, and that may make it appear that I seem to be critical. I do not want my remarks to be considered in that light. Practically my criticism would amount almost altogether to this: That this is hardly a paper to be brought before this Institution; it is of too general a character. It evidently has not been worked out in its full details. The various methods by which the work could be done have not been considered, nor have the details of cost been at all accurately gone into. It does not matter in the slightest that the result obtained with a stationary engine is cheaper than with a locomotive, which is practically the result arrived at in this paper. All I wish to say is that if Mr. Langdon had read this paper before the Society of Arts, or before some popular audience, or had published it in some more popular form, it would have deserved approval in every way, because it draws attention to a subject which has been interesting engineers for a large number of years, and which, although not novel to those who happen to be engaged in those subjects, is novel doubtless to a large number of people generally interested in the matter. I have said that the subject is an old one which is well known to all those who have been engaged in discussing the question of the electric working of railways. If, in elucidating this point, I draw attention to the work that I have done myself on the subject, it is not in the least with the idea that I stand alone. The particular point that has been raised to-night in Mr. Langdon's paper has been common conversation among us all for the last quarter of a century. You will find that the only facts in the paper before us that have not been available for everybody who has been discussing the question for the last quarter of a century are the number of trains that are passing two stations on the Midland Railway. The whole of the rest of the facts are perfectly accessible to everybody who has been discussing the question. And here let me point out, while alluding to those two stations, that Mr. Langdon has chosen the most favourable instance that was within his cognisance to illustrate the electrical side of the question. A most important point has been drawn attention to in the letter which has just been read to you, namely, that no such Professor Forbes.

Professor Forbes.

system for supplying electric power from central stations can, in the nature of it, pay its dividend on the capital invested unless you have a continuous service of trains. If you are going to have only a train or two an hour, or a train every two hours, the stationary engine loses a great deal of its benefit during the idle moments. I will just give you some idea of how people have been working on this subject for many years. I do not in the least wish to push myself forward as having done anything in the matter, but I have taken a note of the things which I happen to have been at work on in connection with the subject. I first drew attention to the desirability of introducing electric traction on lines of railway in a lecture at Glasgow in 1879. In 1881 I communicated to the *Times* an account of the same thing, while in the following year, before the Society of Arts, I drew attention to the same subject. Continually from that time onwards myself and others who are interested in these matters have been discussing this problem, and they long ago arrived at the conclusion which is contained in this paper, namely, that a stationary engine uses less coal than a locomotive engine. After that, it has happened that in the ordinary course of one's profession I have been obliged to investigate very closely the different methods by which such a service can be given. At the time when the City and South London Railway was started, Mr. Greathead invited me to report on the different methods in which that railway might be run. You remember it was originally intended for a cable railway, and that was the first practical case which I had to deal with in which figures of cost and working expenses were wanted. Subsequently I did in a rough sort of way do something in the United States dealing with the same question. During the years 1897–98 I was employed by the Egyptian Government in surveying and reporting upon the capabilities of the Nile cataracts. Lord Kitchener, then Sir Herbert Kitchener, the Sirdar, consulted me about his desert railway from Wady Halfa to Abu Hamed. I pointed out to him that after the first 100 or 150 miles had been laid, out of every four trains which he would be sending from Wady Halfa to railhead, three trains would be carrying nothing but water and coal, and I suggested to him the desirability of introducing stationary engines at Wady Halfa, and laying down wires to work electric locomotives to carry materials for construction. He thoroughly appreciated the idea, and would undoubtedly have carried it out, but time was pressing, and it was impossible to get materials for this work quickly enough. At the same time, while I was engaged upon this service, Sir William Garstin, Assistant-Secretary of Public Works, asked me to pay attention to the feasibility of working the Nile railways by electricity. In that case I had to go extremely fully into the details of capital expenditure and working expenses. I have had to work on the conditions of other railways in different parts of the world in the same way. In 1897 the editor of the *Engineering Magazine*, whom I had not communicated with, happening to know that I had done something in this way, asked me to write an article for that magazine, and I wrote a very popular general account of the work.

"The conclusions derived from study extending over many years are as follows:—

"(1) In cases where water power is always available within a few hundred miles of a trunk line of railway, it is probable that economy would be served by introducing electric traction. Professor Forbes.

"(2) In the case of an independent system of railway to be constructed in a new country utterly unaffected by the traffic from steam railroads, power can be applied to every axle of the train; wherefore it will be economical in such a case, in construction and in operation, to use electric propulsion in preference to steam.

"(3) For desert railways, where water cannot be obtained, electric traction is eminently suitable.

"(3) In underground railways, such as the Baltimore Tunnel and the London underground system, where economy is not so important as convenience and comfort, electricity must be employed; and, where such railways are to be constructed, economy makes electricity advisable.

"(5) In cases of suburban traffic electricity would help to overcome the competition with street railways by supplying the public with separate and independent cars running at very frequent intervals on a well-maintained track."

That is really the same result that has been arrived at by Mr. Langdon and by many others in looking into this question. Mr. Hammond has said that one ought to look into the question of the details of the scheme which Mr. Langdon has put before us. I do not think Mr. Langdon would claim to have gone really into all the different ways in which this could be done, otherwise I would criticise the paper very severely. At any rate, I would put forward very opposite opinions to those which are contained on page 133:—

"Midway in the fifty miles of railway is the central station, containing four 2,500 kilowatt, three-phase, or other characteristic, 10,000 volt generators. At this pressure current is distributed to sub-stations, each serving ten miles of railway, where the potential is converted to 600, from whence it is carried to the contact rail. Or the centre ten-mile section may be provided for by direct-current generators served from the same steam plant."

I can only say there is not a single item there which seems to me to be the right thing for the purpose. I know it is not fair to state things in that general way, but if I were to go into the whole methods by which I consider that such a railway ought to be worked, it would take up far too much time, and would be the result of much more laborious calculation than the paper itself has been. I wish also to say, since Mr. Hammond has said we ought to go into the details a little, that I have looked into some of the figures to a slight extent. I have looked into the £70,000 that he is going to spend on his go and return rail. All that is based upon 600 volts pressure, upon a distance serving five miles from each sub-station, and the general result I get at is that, if it is copper, 6·6 square inches would be required to give 10 per cent. drop at the midway point, which I understand is what he wants. In that case the total expense on the low-pressure conductors, if I have understood the paper properly, would be £330,000 instead of £70,000; but I may have misunderstood some point in the paper, and therefore I will

Professor Forbes.

not say more. I am afraid that I have seemed more critical than I really wanted to be. If this paper had been simply a general paper to the public at large, I have already said it would be a most admirable paper, most beautifully put and expressed, but as there is nothing in the paper that has not been better done before, I hardly think it has gone into sufficient detail, or is sufficiently definite for the Institution of Electrical Engineers.

Mr. Hudleston.

Mr. F. HUDLESTON: I hardly agree with the last speaker that it is unnecessary to deal with details in these matters. I think the chief points that one can deal with in a paper of this magnitude are the details of various savings which Mr. Langdon has put before us. I propose to confine myself generally to the coal consumption that he has spoken of. First of all, last week Mr. Raworth touched upon what I think was a serious mistake in Mr. Langdon's figures. He tackled Mr. Langdon's total output, as shown in the last column of table No. IV., and said that he had made out practically double that amount. He did not follow this to its conclusion, but in my opinion he was right. I think Mr. Langdon has entirely under-estimated the work on heavy railways such as you have to deal with in steam-locomotives. If you look at Table IV. you will find the speed given in the fourth column, the load in the sixth, and the total tractive effort in the seventh. He has calculated out his Tractive Effort on a formula which, as Mr. Raworth pointed out, is fairly correct for high speeds, but is not correct for low speeds. Moreover, he is assuming a perfectly straight road, and a level one. These things do not exist in practice. You have in reality uneven roads, and you have heavy ground to go over. If you divide the tractive effort by the load you will find that Mr. Langdon gives this startling result. He says he is going to deal with a mineral train and a goods train with a resistance of only 5½ lbs. That is an impossibility in railways in England. The ordinary goods train pulled along has a resistance of at least 10 lbs. on a straight road, but on an ordinary irregular road the resistance is increased enormously. The train has to be pulled uphill; on going downhill the brakes must be put on more or less, and in addition there is frequent starting and stopping. Hence the power given out is much larger than the author states—183 H.P. to pull 500 tons. I propose to take my facts from Mr. Johnson's paper, which, as Mr. Langdon remarks, is most valuable for an inquiry of this sort. I have taken chiefly the year 1892. The figures are given in Mr. Johnson's paper, and it will be found that in that year Mr. Johnson carried out for the Midland Railway Company a set of experiments to find out what was the coal consumption on passenger trains, goods trains, and mineral trains. The figures are all set out in Mr. Johnson's paper, and he gives the results in pence per train-mile. He also gives his average price of coal, and if the average cost of coal per train-mile be divided by the price of a pound of coal, the average consumption for the three classes of trains is found. Passenger trains took about 36 lbs. per train-mile, goods trains 53 lbs., and mineral trains 62 lbs. That agrees with all the other results that have been obtained on railways in England—there are dozens of cases. There was a paper read before the Institution of Civil Engineers in

1895 by Messrs. Adams and Pettigrew, in which they gave a set of elaborate experiments on the South-Western Railway. They were trying an express train, and took diagrams during the whole of the run. They found there with a train of about 250 tons weight, that it took about 30 lbs. of coal. It was a fairly easy route, and I expect Welsh coal was used—in fact they say so. Mr. Smith read a paper before the Institution of Mechanical Engineers about two years ago on a similar set of tests on a North-Eastern express of about the same weight—275 tons. There his coal consumption was about 40 lbs., a little higher than in the other case. That was ordinary, good North-Country coal. Then Mr. Webb on the North-Western took a party of engineers up to Crewe with one of his compound engines. Everything was tested pretty closely. The train weighed 420 tons, and the coal consumption was about 44 lbs. per train-mile. All these figures average about the same per ton-mile. In one case it is 0·14, in another 0·105, and on the South-Western about 0·11 lb. The horse-power obtained was, on the South-Western express very nearly 600 H.P., and on the North-Eastern from 550 to 800, which averages over 700. Comparing those figures with the first figure given by Mr. Langdon in his table of 477 they are very different, and I should say a train of that weight will require an average horse-power of about 600 to pull it along. Ordinary passenger trains and empty coaches require very little less power, because they are always starting and stopping, and there is much to be done in acceleration. For a train of that size you should not, at a moderate estimate, have less than 350 H.P. In the next case, Mr. Langdon puts down 295 H.P. for a train of 400 tons at a speed of 35 miles an hour. It is more likely to be over 400 H.P. A mineral train, according to Mr. Johnson's figures, burning roughly the same amount of coal, would come out at about 400 H.P. Any locomotive superintendent would say that a mineral train of that weight would not take less than 400 H.P., and he could probably prove it by diagrams if he chose. Taking these results, we get 6,100 H.P., instead of the total horse-power which Mr. Langdon has got in his last column but one. That agrees fairly well with what Mr. Raworth has said. The net result is, that the power-houses, instead of giving about 5,000 kilowatts, would have to give nearly 9,000. Mr. Hudleston.

Generally speaking, I should say that Mr. Langdon has under-estimated the whole of his power, and that he would require an output of nearly double what he has mentioned. Putting it at 9,000 for the moment, I am afraid the coal consumption of 30 lbs. per train-mile will go up considerably—it goes up, in fact, on my figures to 57. Mr. Langdon, again, calculated on the consumption of 3 lbs. per kilowatt at his power-house. We have not got that yet even in the steadiest load of any power-station in England; but, on a railway, the load is not a steady load. Mr. Langdon has an average of about fourteen trains passing through. The power they take varies enormously from time to time, and a large compound engine, however good it may be, cannot work economically with a load that varies, we will say, from 60 up to 140 per cent. I have known a railway vary from 50 to 150 per cent. on its average. You cannot, under those circumstances, expect to

Mr. Hudleston.

generate your power for as low a coal consumption as 3 lbs. I am sure, at least under our present knowledge of steam and everything else, that something like 4 lbs., or 4½ lbs. per kilowatt, would be used. That brings up the consumption to 85 lbs. per train-mile, instead of 50, as in the case of the Midland at present. There are several electric railways in England, and two of them I know well. Both of them have compound condensing engines in the power-houses; both of them have more trains per hour than Mr. Langdon has, and it is found that their coal consumption does not compare favourably with that of the Metropolitan District Railway. The coal consumption of these railways has been stated at various times from 0·4 up to 0·5 lb. per ton-mile. I think Mr. Cunningham last week gave ½ lb. as the rate for the Central London, and about 0·4 lb. for the Overhead Railway; but Mr. Cunningham was perhaps a little beyond the mark in his figure. Yet taking 0·4 lb. for the work done on these railways, you cannot at once compare with the kind of railway that Mr. Langdon has spoken of, because they are for short distances, with frequent starting and stopping, and have to do an enormous amount of work in accelerating. But the Underground has much the same conditions of traffic. It is practically level from station to station, and has no switchbacking. The Liverpool Overhead Railway is almost the same: it has one switchback length in its line. On the Central London, which runs at a much higher speed than the other two, switchbacking does something like thirty per cent. of the whole power required to pull a train from one end to another at that speed—that is, the switchbacking does most of the work of accelerating. Therefore I say one may take these two railways, the Central London and the District, as a very fair comparison of what can be fairly well done now by electrical engineers. The District Railway does its work at 32 lbs. per train-mile; the Metropolitan does it at 36. The weight of the train is about 135 or 140 tons, very nearly the same as the Central London, and that works out at rather less than ¼ lb. per ton-mile. The District Railway uses the best coal it can get, simply because of the fumes that are given out. I do not think you can fairly claim that the difference between 0·4 and 0·25 lb. is entirely due to the South Wales coal, though I would ascribe a certain amount of it to that. I think that the electric railways I am dealing with, if they were burning good South Wales coal, would probably get down to very nearly 0·3, but they would have a difficulty in getting past 0·25 lb. This agrees pretty well with what I put down for the figures on this ideal railway. I think myself that Mr. Langdon has under-estimated it considerably. With our present knowledge of electricity and steam, I do not see how one can expect to get an economy of that sort. I believe in a very short time we may get down to the same coal efficiency, but I do not think it will be surpassed, and therefore I think that this particular economy must be wiped off the sheet. After that, I admit all the other things are an advantage—the electrically driven lines are cleaner, and sweeter, and the hauling is more regular. The dirt is got rid of, and there is not the same wear and tear. As regards repairs and so forth, we have had no experience yet to judge, but Mr. Langdon, fairly enough, assumed that they will be about the same. I think the coal economy is not

proved in the least, and that many of the other economies will hardly stand close inquiry. Each particular item of Mr. Langdon's paper—I do not agree at all with the last speaker—is worthy of criticism. Mr. Hudleston.

Mr. A. A. C. SWINTON: I would like, at the outset, to say I do not agree with Professor Forbes that this is a paper not suited to this Institution. I think that it is not only eminently suited, but that it is one of the most interesting and suggestive papers we have had for a very long time. About a year ago I had a conversation in London with a very eminent authority upon matters of this kind—Mr. George Westinghouse; and, as far as I could gather, he did not appear to contemplate the possibility of the adoption of electricity for driving trains upon main lines. He thought that very shortly suburban traffic would be almost entirely done electrically, but he did not seem even to have contemplated the use of electricity for driving trains on main lines, such as is dealt with in this paper by Mr. Langdon. Only about a year ago I had occasion to look into this question in connection with a contemplated railway, and made some estimates as to what the scheme would cost. Curiously enough the line was to be exactly the same length as that portion of the Midland Railway which Mr. Langdon has taken as his basis in the paper before us—it was just over fifty miles. After a careful computation, I came to the conclusion that the total cost of the equipment would be little more than Mr. Langdon has stated—namely, just over £523,000; but there the resemblance, I am sorry to say, ceases. I must confess that I cannot understand Mr. Langdon's figures in regard to the subject to which Professor Forbes has already drawn attention. I cannot understand how he is to make the necessary arrangement for cables and contact-rail for £140,000, and I think it would be very interesting if Mr. Langdon would give us further details as to what is included in those two items. In my case, the power was much less, as there were fewer trains running at one time; and although my total came to very much the same as Mr. Langdon's, a much smaller proportion was represented by generating plant, and a very much larger proportion by plant for distribution, by which I mean cables and "trolley wires." Mr. Swinton.

There is one way in which, I think, some economy might be derived of which Mr. Langdon has not taken advantage. Mr. Hammond mentioned a railway where they are going to employ 3,000 volts upon the motors, and I do not know anything, except perhaps the rules of the Board of Trade, to prevent the use of a considerably higher voltage than 600 upon the motors; and if, in addition to using higher voltages on the motors, we can also successfully use three-phase motors and save the rotary transformers, there will not only be a considerable saving in capital, but there will also be an increase in efficiency, and, more important still, there will be no necessity for any assistants at the sub-stations. Rotary transformers necessitate the employment of assistants, but static transformers can be shut up and left to themselves, and that will make a considerable difference in the cost of running the concern. The evening this paper was read, I happened to meet Mr. Charles Brown, and thinking it a favourable opportunity to ask him about the Burgdorf-Thun Railway, I inquired whether, if he had to equip

Mr. Swinton. electrically a main line in this country, he would use the same system; and he replied that, unless there were any very exceptional circumstances which did not occur to him at the moment, he should certainly use three-phase motors, and not continuous-current motors and rotary transformers.

The question raised by Mr. Robinson as to whether there is economy in large stations is a very important one. Some of us spent many weeks last year in trying to persuade a Committee of the House of Commons—and we did persuade them—that there was economy in large stations. If there is no such economy, I can see no advantage in Electrical Power schemes. Some people seem to think that the whole matter is merely a question of how many pounds of coal are required to produce a horse-power in an engine; but the coal expenditure is but one item out of many. There is the question of capital cost. Does Mr. Robinson suggest that a station for 10,000 kilowatts costs ten times as much as one for 1,000 kilowatts? [Mr. MARK ROBINSON: It costs twice as much as one for 5,000 kilowatts.] I cannot concede even that. In dealing with 10,000 kilowatts you can afford to do all manner of things that you cannot with 1,000, and which you cannot do so well with 5,000 kilowatts. At the end of three weeks the condition of the mind of the Committee to which I have referred was that at about 10,000 kilowatts the *rate of increase in* economy began to slack off. But that is not my opinion. I should not be inclined to put it below 50,000 or 100,000; indeed I am not sure you can put it anywhere. The bigger the plant is, the easier it is to arrange all manner of different economising devices, such as superheating, coal-conveying apparatus and the like.

I would also like to ask how, with stations all along the line (as Mr. Hoy suggests, with stations about every mile), a constant load is to be obtained. Each station will be working for about five minutes, and then it will have to shut down. A constant load can only be ensured by having one station to work a great length of line, and it is only by securing a constant load that proper economy can be obtained.

Mr. Walton. Mr. A. H. WALTON: I cannot agree with my friend Mr. Hammond, who has previously spoken, that everything is just as it should be in this paper. Mr. Langdon has certainly put it before us in a very broad manner, but I think he has got wrong over his tractive effort. His figures for mechanical horse-power are, as Mr. Hudlestone said, far too low. I will give you an instance. Take his express train having a H.P. of 477. That works out as low as 26 watt-hours per train-mile. I do not think it has ever been done yet at that figure. The best we know of up to the present time is a little under 40 watt-hours per train-mile. Molesworth's formula, defining the resistance as lbs. per ton $= \frac{V^2}{171} + 8$, level, gives a tractive effort for that express train of 22·6 pounds per ton, which is somewhere near Mr. Hudlestone's figure. Mr. Hudlestone mentioned the figure of 827 against Mr. Langdon's 477. If we go still further, and work out the watt-hours per train mile, Mr. Langdon's come out at 26, whereas Molesworth's come out at 44·8, which, I think, is near the mark. I think you will agree with me that Mr. Langdon has altogether under-

Mr. Walton.

estimated the power required for the tractive effort. It is true his comparisons are with actual data at his disposal in Mr. Johnson's paper, that is to say a mechanical H.P. costs so much a train-mile with a given weight, but he has had to estimate the electrical side of the question, and his estimate is altogether too low; indeed, I think with Mr. Hudlestone, it ought to be wiped off the sheet. With regard to Mr. Langdon's statement on the question of coal, he has put down 3 pounds per kilowatt-hour; but I agree with Mr. Huddleston that from 4·5 pounds to 5 pounds would be considered fairly good in practical working. I think we shall be very well satisfied if we get it in the many projects that are before us and, at the same time, reduce some of the stations that are already running to that figure. I do not think 3 pounds per killowatt-hour has ever been accomplished. Mr. Cunningham told us that on the Central London Railway the watt-hours per train-mile were 70, irrespective of the lifts and lighting. Ever since we completed that line under Mr. Hudleston's supervision we have been watching it very carefully, and we find that the watt-hours per train-mile are 64·9 actually generated for everything, and we find an average at the third rail during the last two months of 50 watt-hours without the lighting of the train. That average has been checked by one-second readings during three or four runs with the motor from the Bank to Shepherd's Bush and back, and the figures actually came out at 49·5 after checking instruments, so that I do not think we are far wrong. Mr. Cunningham also told us that the coal was 0·5 lb. per ton-mile. Mr. Hudleston, I think, has already said something in reference to this. In watching this point we found that the actual coal per kilowatt-hour was 0·44 pounds, which works out at 6·6 pounds per kilowatt-hour. That, of course, is high. Here I would venture to suggest that we seem to be talking in the dark on this question of coal. We heard Mr. Hudleston speak of what can be accomplished with Welsh coal, and he said that we could not get down to a particular point if cheaper coal were burnt; but in this instance it is entirely due to the very cheap fuel which is being used. I venture to suggest that if we could standardise this question and speak of the cost of the coal, and not of the weight of the coal, it would be much better. We are all burning different kinds of coal, and no one gives the calorific value. One is burning Welsh coal, and another is burning practically dirt.

There is just one other question I should like to touch on. On page 135 the author suggests $2\frac{1}{2}$ per cent. leakage on his line, which I consider is very excessive. Taking the five sections given at Figure 2, that amounts to 35 amperes per section, or on the total line 170 amperes, and taking the resultant of the E.M.F. over the current which is passing through, we get the most extraordinarily low insulation result of 3·5 ohms. I ask, Is any line going to work on that? I am afraid Mr. Langdon has rather overdone it in the case of leakage; and that he has been too liberal on the electrical side.

Mr. Lawson

Mr. A. J. LAWSON: We have all to thank Mr. Langdon for his paper. While I agree to some extent with Mr. Hudlestone and others that the author has taken too low a figure for coal consumption, I think he has, on the other hand, done some injustice to his own cause by assuming

Mr. Lawson. much too low an efficiency in his motors and in his method of transmission throughout. For instance, he has taken the motors with 85 per cent. efficiency; the ohmic loss in transmission at 10 per cent.; leakage $2\frac{1}{2}$ per cent.; loss in rotary converters 10 per cent.; in static transformers 7 per cent., and in high-tension transmission 10 per cent. I think he might very well have assumed that he could get nearly 90 per cent. in motors; a line loss of 5 per cent., even assuming that he has his insulation resistance as low as Mr. Walton put it. He could get 97 per cent. efficiency in his static transformers instead of 93; 93 per cent. in his high-tension transmission instead of 90; and 71·35 per cent. over-all efficiency instead of the 58 per cent. he assumes. If, however, he adopted a three-phase transmission, eliminating altogether his rotary converters, and taking his own efficiencies, he could still obtain 62 per cent. instead of 58; this gain may not be very great, but it is an addition of $4\frac{1}{2}$ per cent. In taking the efficiencies I have assumed, he could get 75 per cent. over-all, which will go very far towards reducing the coal bills that I am rather surprised the apostles of electric traction in this assembly are so very desirous of putting up. I cannot understand their object. Is it that they are not ready to meet the case of electrical equipment of main lines of railway? It has been done on the Continent. As Mr. Swinton has mentioned, high-tension, three-phase transmission has been in fairly successful use on the Burgdorf-Thun Railway, and a higher voltage, four times as much as on the Burgdorf-Thun line, is going to be put into use on another line next month, I hope. We shall then gain some information which will be useful, and although the station is a water-power station, I think it will dispose to a very large extent of the suggestion of separate stations at intervals of every five miles. Not only will they save the attendance which Mr. Langdon has estimated for at every one of his sub-stations, but with generating stations, as Mr. Robinson suggested, for every ten miles (which, as Mr. Swinton has justly pointed out, will mean a station loaded for a few moments and unloaded for the greater part of the hour) there will be a coal consumption in excess of the figures which have been mentioned by Mr. Walton and others. With a station every ten miles or so you might just as well retain the present locomotives—indeed, I think it would be better to do so, because you would otherwise have the assistants not only on the locomotives but at the sub-stations increased in number.

Mr. Siemens. Mr. A. Siemens: I would like to draw the attention of the meeting to the fact that the title of the paper is "The Supersession of the Steam by the Electric Locomotive," while the discussion has now entirely branched off into a statement of the fact that where a line of railway has eleven or twelve trains per hour, it is cheaper to run it electrically than by steam. That, I think, we all know. As Professor Forbes has already pointed out, that does not want proving. Mr. Langdon can afford to give the £330,000 for his conductors, which I think is the proper figure, and he can afford to wipe off the coal saving, which does not exist according to my idea, and still he will show a saving on such a line. But he proposes in his paper that the

Midland Railway Company, for instance, should go on converting its line gradually fifty miles by fifty miles. Is he going to stop his Scotch expresses at Bedford to change engines when he has completed the first stage? What also is he going to do on those portions of the Midland line where there are very few trains—only two or three per hour? I think what Mr. George Westinghouse said a year ago is still absolutely true, that for suburban traffic, for any traffic which has something like ten or twelve trains an hour and upwards, it is natural that electric traction will come and that electric traction is the proper thing; but for the long main-line trains, for those parts of the railway system where there are only a few trains per hour, I do not think there is any chance yet of introducing an economical system of electric traction. Mr. Siemens

Major P. CARDEW: I think Mr. Walton and Mr. Hudlestone possibly have been misled as regards this column in Table IV., Mechanical Horse-power per Train Hour. Major Cardew.

Mr. LANGDON: What I was desirous of expressing was the fact that that power was required for an hour. The table seeks to reduce everything to an hour's work, and therefore the horse-power is not intended to express exactly what is the maximum horse-power being used at any time in kilowatt-hours. Mr. Langdon.

Major CARDEW: I think that one important thing to notice in the tables given in the paper is the extremely small number of miles over which each locomotive is run in the week. I find from them that on the North-Western Railway they only use each locomotive for 314 train-miles per week. Taking into consideration the time of the drivers and the firemen, the wages table comes out enormously high, and I do think a considerable economy is possible with electrical traction. Apart from the possibilities of absolutely reducing the employés on a train (which, I think, is quite within contemplation, seeing that the work to be done is reduced to practically nothing), there is much time lost by the steam locomotive before starting and after returning to the shed and during the time it is taking in water and coal. I find that in most railways they allow three-quarters of an hour for the driver and fireman before starting, and the same time after the engine has returned to the shed. All these little items mount up. Major Cardew.

Mr. Langdon deals with the traffic as it exists. If it were really in contemplation to equip a line electrically, no doubt it would be possible to find out how the service could be best suited to the new means of working, and the tendency would be to run shorter and more frequent trains. Then, with regard to the terminal stations. With motor-cars at each end of the train, it would be possible to clear the train out of the station in very much quicker time than it takes to shunt an ordinary train with a locomotive. Much could thus be saved. In the same way the goods traffic could be arranged on much better lines for electrical working. I find that a great deal of use is now being made on the Continent of locomotives with accumulators for shunting purposes, and of course they fulfil a very desirable object. In shunting, neither power nor speed is required, but only a good horse, as it were, to drag the trucks about, and an accumulator locomotive does the job and saves a great deal of expense in the equipment of sidings. I may

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Major Cardew.

say that I have seen the experimental line at Buda Pesth and closely studied it, and am quite satisfied with the working. The working is admirable, and by the arrangement of the three-phase motors in series, whereby they tend to halve the speed, a great economy is effected in the starting. The same thing comes into operation in the stopping; the other motor is switched in in series, and the immediate effect is the return of power to the line. In that way the three-phase working certainly has an enormous advantage over the ordinary continuous-current system.

Mr. de Segundo.

Mr. Ed. C. de Segundo: The author has attacked a subject which, in my judgment, is destined in the near future to be one of national importance, and I trust that he will accept my assurance that any remarks I may have to make on his figures are made with due deference to the opinions of one so much my senior in age and experience. First with regard to the important subject of coal consumption, Mr. Langdon has put down the figure of 3 pounds per kilowatt-hour. I have looked up some figures, and find that the consumption of coal per kilowatt-hour at the Central Station of the Dublin Railways works out to 2·1 pounds on the basis of the boilers evaporating 8 pounds per pound of coal. At the Dortmund Electricity Works it is 2·8 pounds per kilowatt generated; on the Berlin tramways it is 2·3 when using saturated steam, and with superheated steam 2·1. It must be remembered that these are test figures. I have worked out the average consumption of coal per kilowatt-hour distributed on seven of the more important central stations on the Continent, including Berlin, and I find that it works out at 4·5 pounds. This seems to point to the fact of Mr. Langdon's allowance of 3 pounds being somewhat narrow; but on the other hand one has yet to be quite sure what the load-factor will be in the circumstances in which Mr. Langdon's figures are conceived—the application of electric traction to a railway.

So far, the application of electric traction has been made under conditions which, so to speak, have been in favour of electricity—that is to say, the railway has been built for an electric railway, and there is not a sufficiently extended record of the performance of electric locomotives doing railway work under the conditions which obtain in any ordinary main line, so that we can only hazard a guess as to the nature of the load-factor which will obtain in those circumstances. Mr. Langdon has not suggested how freight-traffic is to be dealt with, and through-traffic is also an important point. Both of these contribute very largely to revenue: in fact, the revenue from freight-traffic may be 2½ times or 3 times that which is obtained from passenger-traffic, and the through-traffic may be from 45 to 50 per cent. of the whole traffic of the line. While the tendency is more and more towards short, frequent, and consequently light trains for passenger-traffic, which is admirably suited to electric traction conditions, the tendency is to increase the length, and consequently the weight, of freight-trains and to run them at longer intervals. Of course from a steam railway point of view the economic aspect of this is apparent on the face of it. But, with electric traction, it is obvious that the frequent starting of these heavy freight-trains would be a factor operating disadvantage-

ously to the economy of the steam engine at the generating station. On the other hand, there is one point in favour of electricity I do not think anybody has referred to yet, and it is a very important one. We all know that only about half of the total weight of the locomotive and tender is available for tractive purposes; in the electric locomotive it is possible to apply the whole weight on the driving axles. Therefore the conclusion will be obvious that for a given tractive effort an electric locomotive need only be half the weight of a steam locomotive; and I need hardly point out the reduction in the wear and tear of the permanent way, and the consequent saving of expense of the cost of maintenance, that would result from that alone. The total absence in electric traction of "pounding," which it is impossible to avoid in the steam-locomotive, due to unbalanced piston-effort, would operate largely towards a reduction in the cost of maintenance of the permanent way. With regard to this complex question of large or small stations, I merely throw out the suggestion that should such an event be contemplated as the supersession of all steam locomotives on a line like the Midland by electric locomotives, it might be possible for the electric generating stations in some of the big cities and towns through which the railway passes to contribute in some measure to the current necessary for traffic purposes. This does not remove the objections I have raised before; but it is a possible means of reducing the capital expenditure of a railway company which contemplates such a step by making use of existing sources of supply. Mr. de Segundo.

With reference to the financial aspect of the question; during recent visits to the United States I have on every occasion been struck by the fact that our American cousins seem to have anticipated the fact that the future is pregnant with big events, and they have made preparations to cope with any demand that may arise. We in England have not kept pace with the times, and if we are to recover our position—I use the word advisedly—we should tear from our eyes the veil of pride and prejudice which prevents us realising our own deficiencies, and consent to learn from our neighbours, notably the United States, so that we can regain the trade we have lost, and re-establish our position of commercial supremacy amongst the nations of the world.

Mr. FRANK SPRAGUE: I have not had the time to criticise this paper, and I prefer not to do so. In considering any electric railway proposition, the practical question always stares me in the face: How is one to accomplish a result, and is it worth the while? Being possibly somewhat of an enthusiast on matters of electric traction, having given a number of years to the subject, there is no attempted solution of problems of this character, whether concerning suburban or main-line service, that does not command my interest, and I always welcome the various proposals made. Mr. Sprague.

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Mr. Sprague. capable, and you gentlemen who are consulting engineers prescribe very rigid conditions of test. It must run for so many hours, at a certain speed, and a certain output; it shall have a certain capacity of excess, and so on. In short, the machine must be of permanent character, built for years of continuous service. With a stationary motor, similar requirements exist. It must be a machine which, hour after hour, shall be able to deliver a certain horse-power. On the contrary, whether it be because of a misconception of what electric railways demand, or because actuated by a somewhat unnecessary commercial instinct, the manufacturers of electric railway-motors have adopted a unique method of rating. For example, we hear of motors of 50, 75, and 150 H.P., the latter being probably amongst the largest of the units which are regularly built for railway service. These ratings mean little except that, for example, a 100 H.P. motor, railway-standard, can for an hour do 100 H.P. of work, and can stand a 50 per cent. excess of load for another ten minutes, but that is not, properly speaking, the rating of a railway-motor, as has been shown in a very interesting manner by Mr. John Lundie, who has made a special study of the kinetics and requirements of heavy electric traction.

Common sense teaches us that if the electric motor is put against the steam-locomotive, it must be a machine capable of equal continued service, and it should be rated in a general way the same as any other electric machine, on its average, as well as its special, capacity. If a small railway-motor is rated in a certain way by the hour-basis, a larger one tested under the same conditions has a fictitious and excess rating compared with the smaller one. Speaking generally, any steam or electric railway-motor should have as a measure of its rating what it can do hour after hour on active service.

Looking at Table IV., there seems to me to be a rather curious series of figures, and I quite agree with Mr. Hudleston that they are under-estimated in the matter of actual H.P. required. The method of determining train-miles per hour by multiplying the trains passing a given point by the running speed is erroneous.

What is an electric locomotive? It is simply an assemblage in which is localised a multiplicity of motors, generally four motors on four drivers, the motors being built to fit spaces which, because of the conditions under which the motor has to be operated, are restricted by wheel dimensions, wheel base, track gauge, distance between wheel seats, transom and axle, and there is a very definite limitation to the size of a motor so determined. To illustrate this fact, take, for example, one of the largest types of motors now built, rated at 160 H.P. For continuous service, and with an excess of temperature of say 75° C. above the surrounding atmosphere, it can stand about 35 kilowatts of continuous average input, or develop an average of, say, 40 H.P. available for effective traction.

I think that it is safe to say that the electric locomotive will not generally take the place of the steam-locomotive. If a steam-railway adopts electric traction, it must radically change its service; it must adopt smaller train-units, complete within themselves, operated independently, or in combinations making up longer trains. Then one

must do what is done with a hand-controlled locomotive, use a multiplicity of motors, but a greater number, distributed on the different cars or motor-car units. As soon, however, as this condition is determined, direct hand-control must be wholly or partly abandoned for general work, and the motor equipments put under a secondary control. We have to face the very practical fact that we cannot, without unnecessary restriction, compress upon a single unit the power that is necessary to do the service that is done by a steam-locomotive to-day. I of course do not agree with the last speaker that an electric motor can be built of half the weight of the steam-locomotive, that is if it is to do equal service; but it is perfectly possible—and it is being done every day—to consolidate any number of units equipped with any required amount of power, under a common control. Mr. Sprague.

It is not sufficient reason for adopting electric traction to say that you can save some coal, for in many instances, especially with long trains, I question whether you can save a dollar's worth. The question of coal is a secondary one. What is all-important is capacity for increased speed, and the making of train-lengths and train-intervals subject to the will of the train-manager—in short, the ability to get and to accommodate traffic and service. I repeat that the electric locomotive on a trunk-line service has not a promising future. That service itself must be changed with change of motive power. The question reduces itself simply to the number of units which are in operation between two points. If the units are few in number, electric application is not generally to be considered. As the number increases sufficiently, then there will be a field for electric application, and then only.

Professor C. A. CARUS-WILSON: There are, in my opinion, three reasons why the supersession of steam by electricity on the railways of this country will take place first, not on the main lines, but on the branch lines. Prof. Carus-Wilson.

In the first place, the branch lines, or, to be more specific, the cross-country lines, as distinguished from the main lines, are the least profitable part of any great railway system. And since it is the wisdom of economic railway management to ascertain what is the least profitable part of the system, and make it, if possible, more profitable, it will always be to the interest of the great railway companies to endeavour to make the branch lines pay better, in comparison with the main lines, than they do now.

A few figures will show that the branch lines are, as a rule, far less profitable than the main lines. Taking the Board of Trade Returns for 1899, we find that for the Midland Railway the average profit per passenger train-mile is about tenpence. Taking the average number of trains per day, each way, on branch lines, as six, the profits from the passenger service per mile per day is five shillings. On a main line, on the other hand, the number of passenger trains each day might be taken at thirty each way, making the profit per mile each way twenty-five shillings, five times that of the branch lines. No doubt this is a rough estimate, but it is probably not far from the truth. Hence in considering the possible economy to be effected by the introduction of elec-

Prof. Carus-Wilson.

tricity, it will be more to the interest of the companies to endeavour to make their branch lines more profitable, than to make changes on their main lines, which are at present relatively very remunerative.

The second reason I would give for cross-country lines being dealt with first is that the cross-country lines are mainly responsible for the unpunctuality which is such a feature of our railways. I cannot attempt to establish this statement fully here to-night, but may put it briefly thus. The limited traffic on the cross-country lines does not admit the provision of a staff adequate to deal with the traffic. If the traffic were spread out over the whole working day the staff would be sufficient, but it comes all with a rush at infrequent intervals, the result being delay and unpunctuality, especially during the holiday seasons.

The infrequent service and the unpunctuality on branch lines has made cross-country travelling most unpopular, with the result that these lines are now being menaced by the tramway systems which are being projected in all parts of the country. This is a third and most powerful reason why railway managers will be obliged to consider seriously the possibilities of electricity on branch lines.

The remedy for the unpunctuality and the unpopularity of the branch lines is to be found in a more frequent service. To make proper connections with the main-line trains the service on the branch lines should be increased from an average of six trains each way per day to at least twenty-four—that is, a half-hour service instead of a train every two hours. The question is, can this be done by electricity at a profit?

To answer this question, we must know how much each mile of line contributes as profit, from its passenger service, to the general revenues of the railway, and also how much each mile must earn in order to pay its share of the fixed charges, such as maintenance of permanent way, etc. We shall probably not be far wrong in taking five shillings per day-mile as profit, and eleven shillings per day-mile as the contribution towards the fixed charges on a branch line with six trains each way per day. If, now, the running cost per passenger train-mile, that is, the locomotive charges and the guard's wages, be put at elevenpence, a traffic equal to 264 third-class passengers will be required per day-mile each way. We may, then, take this to be the traffic on a branch line as at present run by steam.

For a service of twenty-four trains per day the fixed charges and the profit per day-mile will remain the same, if the branch is to yield no more and no less profit than before, but the running charges will increase in proportion to the number of trains, and for twenty-four trains will require an income of 24×11, or 264 pence per day-mile, which, added to the fixed charge, makes 462 as the required number of third-class passengers per day-mile—that is, an increase of 75 per cent. in the traffic as compared with that required for six trains per day. The traffic must exceed this if the altered conditions of working are to yield an increased profit per mile.

Now the whole difference introduced by electrically driven trains is that the running charges are less. If motor-cars with substantial trailers are used, as on the Burgdorf-Thun line, weighing, say 50 tons,

with only a conductor and motor-man, the running charges should not exceed sixpence per train-mile. Taking this figure, we find that the number of third-class passengers required to yield the same profit and fixed-charge income per day-mile as before is 342, or an increase of 30 per cent. over the existing six-train service. Now a service of twenty-four trains each way per day might safely be relied upon to induce an increase of traffic of 30 per cent. over that of a six-train service. Anything beyond this will increase the profit per mile; thus an increase of 52 per cent. in the traffic would double the profit on the line, and an increase of 75 per cent., which with steam-driven trains would not augment the profit at all, would result in a trebling of the profits. Prof. Carus-Wilson.

The right course, then, seems to be to begin on the branch lines first, to break up the system of infrequent and heavy trains hauled by steam locomotives, and substitute lighter trains running at least four times as frequently, driven by electric motor-cars. The increased traffic would be handled with far greater ease than the existing traffic,

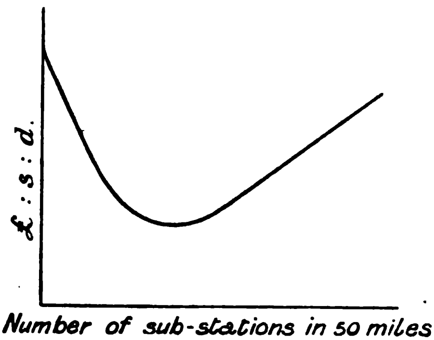

FIG. A.

because it would be more distributed over the whole day. The service would be punctual and popular, and with these advantages there is little reason to doubt that it would be profitable.

Mr. A. P. TROTTER (*communicated*): Mr. Langdon has treated the problem on broad lines, and has not obscured it by detailed consideration of special points. It is quite sufficient for his purpose to assume five sub-stations, without proving that this number is better than four or six. Since he does not give data from which such proof might be established, and since I have no such data at hand, I do not propose to criticise his assumption, but to make some general observations on this point. Mr. Trotter.

If the number of sub-stations on a fifty-mile line be increased, the first cost and sub-station labour cost will be increased, the load-factor of each will be smaller, and the ohmic loss in high-pressure feeders is increased, but the much more important loss in the working conductor is reduced, and this conductor might be reduced in size and cost; and the pressure is more uniform. If the number of sub-stations be reduced, the first cost and sub-station labour cost is reduced, the load-factor will

Mr. Trotter. be greater, while the ohmic loss is increased up to the limit when no sub-stations are used. The working conductor would have to be increased to avoid excessive fall of pressure, but this case can hardly be said to have even that indifferent kind of interest known as academic. All of the factors have a monetary value, except the variation of pressure to which no such value can be easily assigned. That uniformity of pressure is important in some cases is proved by the large number of sub-stations on the Burgdorf-Thun line, but these are inexpensive and require no labour.

Given the necessary data, the conditions for minimum total cost (capital and working) may be calculated. Differential calculus will show the exact number, which is of little interest and no use. Plotting a few examples on a curve (Fig. A) will show whether the curve has a sharp or a flat bottom. It will probably be found that the bottom is flat enough to allow several external considerations, such as choice of site and neighbouring gradients, to influence the decision on the number of sub-stations.

It is probable that the number of sub-stations indicated by the mere question of cost will yield a sufficiently uniform working pressure. In tramway work the uniformity of pressure generally takes care of itself, and is the outcome of other conditions. But such conditions may perhaps show that a uniform working pressure is difficult to attain in railway work. It is said that for three-phase motors no large reduction of working pressure is safe, but for continuous current, considerations of economy and of speed allow no little latitude. It is obvious that it does not pay to level a railway through undulating country, gradients are inevitable, and they control the speed. How far will it pay to level the working pressure? If economy demands widely spaced sub-stations, variation of pressure on the working conductor and consequent variation of speed may be a feature of the railway practice of the future. There is a good deal of difference between the maximum safe speed and the economically best speed on a well-built line. It may be an economy to space sub-stations more widely on level country, and, with suitably designed motors, to allow much larger variations of working pressure than are to be found in modern tramway practice.

Mr. Tyler. Mr. E. H. TYLER (*communicated*): I beg to share Mr. Hudleston's opinion that the electrification of main railway lines is not at present a promising field of electrical development. In any case the suburban and cross-country lines have an overwhelming claim to be treated first. But there are objections to such a sweeping change as the electrical equipment of our main lines which, I believe, have not yet been mentioned. In most European countries the railways, if not actually Government property, are under their close control, it being recognised that railways are part of the national scheme of defence.

It will not, I suppose, be pretended that an electrically equipped line is not more liable to be disabled than a steam line. The characteristic of the breakdown of a system supplied from a central source of energy is general paralysis as distinct from local injury.

There are many main lines in England that are subject to floods,

and it is obvious that it would be easier to throw an electric railway out of gear than a steam line. Mr. Tyler.

These serious considerations, as well as there being no really pressing necessity for the change, lead me to believe that the electrical equipment of our main lines is not yet within sight. The frequent reference to the Burgdorf-Thun railway as an example of main-line electrical traction is misleading. It is a full-gauge passenger and goods line, but in no sense is it a main line such as the Midland or Great Western.

Major Cardew's account of the three-phase line at Buda-Pesth was most interesting, especially his reference to the placing of the motors in series at starting and during retardation. It is not easy to see how this arrangement can return current to the line, inasmuch as the energy returned must be of the same periodicity as the line. But in any case the return of energy can only be carried down to half speed, whereas with continuous currents the regeneration can be continued until the train has nearly come to a stop.

As regards Mr. Sprague's remarks on locomotives, it is, as he points out, almost entirely overlooked that the power that can be exerted on the axles of a locomotive is strictly limited by the dimensions of the gauge and the permissible length of the wheel base. The claim of Mr. Sprague's multiple unit system is that a train composed of traction units shall have the same tractive characteristics as a single unit. Applying this test to railway trains, I would ask Mr. Sprague what he considers a railway unit to be. Obviously not one coach. If we take one half of an ordinary train to be a railway unit, and provide a locomotive of suitable weight and power to draw that unit, it follows that a full train of two units can be drawn by two locomotives coupled and controlled as one,.with the same characteristics of speed and torque as the single-unit train. That appears to me to be the true solution of the principle of multiple unit control, rather than the multiplication of motor coaches. It cannot be forgotten that the adoption of motor coaches entails a wholesale scrapping of rolling stock which no company will care to face. Moreover, for many years the service on electrical lines must necessarily be a mixed one, or at all events through traffic will have to be provided for. The electrical locomotive, although not an ideal application, seems therefore to be a necessity.

Mr. H. A. Humphrey (*communicated*): It is admitted that the supersession of the steam by the electric locomotive is primarily one of costs. Table V. giving the cost of generation and distribution of current, is therefore of vital importance, and should have received special care; yet I regret to find it is the most disappointing part of the paper. Mr. Humphrey.

The first inspection of the table would lead one to say that the cost of generating a kilowatt-hour had been taken at 0·1574d. This, however, is not so, for the cost of oil, waste, and sundries is placed at the bottom of the page, and is not included in the total along with coal and water, although the one is as necessary to the engines as the others. Then there is no item for repairs and maintenance of the generating plant included in the table, and in seeking for this important item we

Mr. Trotter. be greater, while the ohmic loss is increased up to the limit when no sub-stations are used. The working conductor would have to be increased to avoid excessive fall of pressure, but this case can hardly be said to have even that indifferent kind of interest known as academic. All of the factors have a monetary value, except the variation of pressure to which no such value can be easily assigned. That uniformity of pressure is important in some cases is proved by the large number of sub-stations on the Burgdorf-Thun line, but these are inexpensive and require no labour.

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These serious considerations, as well as there being no really pressing necessity for the change, lead me to believe that the electrical equipment of our main lines is not yet within sight. The frequent reference to the Burgdorf-Thun railway as an example of main-line electrical traction is misleading. It is a full-gauge passenger and goods line, but in no sense is it a main line such as the Midland or Great Western.

Major Cardew's account of the three-phase line at Buda-Pesth was most interesting, especially his reference to the placing of the motors in series at starting and during retardation. It is not easy to see how this arrangement can return current to the line, inasmuch as the energy returned must be of the same periodicity as the line. But in any case the return of energy can only be carried down to half speed, whereas with continuous currents the regeneration can be continued until the train has nearly come to a stop.

As regards Mr. Sprague's remarks on locomotives, it is, as he points out, almost entirely overlooked that the power that can be exerted on the axles of a locomotive is strictly limited by the dimensions of the gauge and the permissible length of the wheel base. The claim of Mr. Sprague's multiple unit system is that a train composed of traction units shall have the same tractive characteristics as a single unit. Applying this test to railway trains, I would ask Mr. Sprague what he considers a railway unit to be. Obviously not one coach. If we take one half of an ordinary train to be a railway unit, and provide a locomotive of suitable weight and power to draw that unit, it follows that a full train of two units can be drawn by two locomotives coupled and controlled as one, with the same characteristics of speed and torque as the single-unit train. That appears to me to be the true solution of the principle of multiple unit control, rather than the multiplication of motor coaches. It cannot be forgotten that the adoption of motor coaches entails a wholesale scrapping of rolling stock which no company will care to face. Moreover, for many years the service on electrical lines must necessarily be a mixed one, or at all events through traffic will have to be provided for. The electrical locomotive, although not an ideal application, seems therefore to be a necessity.

Mr. H. A. HUMPHREY (*communicated*): It is admitted that the supersession of the steam by the electric locomotive is primarily one of costs. Table V. giving the cost of generation and distribution of current, is therefore of vital importance, and should have received special care; yet I regret to find it is the most disappointing part of the paper. Mr. Humphrey.

The first inspection of the table would lead one to say that the cost of generating a kilowatt-hour had been taken at 0·1574d. This, however, is not so, for the cost of oil, waste, and sundries is placed at the bottom of the page, and is not included in the total along with coal and water, although the one is as necessary to the engines as the others. Then there is no item for repairs and maintenance of the generating plant included in the table, and in seeking for this important item we

Mr. Humphrey. find that no definite figure is anywhere given, but it is dealt with along with the locomotive charges.

As a matter of fact Mr. Langdon's figures for the cost of energy from a steam-driven central station cannot be considered as constituting a safe basis for calculation. I have studied the question in this country, on the Continent, and in America, and have obtained figures at first hand from the chief engineers of large American traction stations. As a result I entirely endorse Mr. Cunningham's statement that 0·25d. per kilowatt-hour is the limit at present practically attainable in a steam-driven plant. In the case of one of the largest electrolytic plants in this country with the best modern engines and boilers and cheap coal, this figure was not quite reached even with 100 per cent. load-factor and in a year of cheap coal. The figures for the year in question were given to me by the engineer, and included no fixed charges. One of the most reliable statements of costs I know of is that given by Mr. R. W. Conant in his paper on "Cost of Electric Power for Street Railways," read before the "America Street Railway Association" in September, 1898. Mr. Conant examines and tabulates the costs from forty-four of the large traction stations in America, and he found the lowest operating cost per kilowatt-hour at the switchboard was 0·52 cents. (0·26d.). Mr. Conant describes a "standard station," and gives a standard set of figures as being the best practical. These figures come out at 0·58 cents. for operating cost and 0·405 cents. for fixed charges, making a total of 0·985 cents. (0·49d.). The load-factor is taken at $33\frac{1}{3}$ per cent., and the following statement is made :—"As this station is described its performance may seem to border on the ideal, and there is no question but that its performance is consequent on favourable circumstances, very nearly, we may say, test conditions."

To reach figures much below these a radical change is necessary, and as one attempt at the solution of the problem I would direct attention to the use of large gas-engines and Mond gas-producers. The Mond plant employs cheap bituminous slack, and recovers the ammonia in such large quantities as to allow a profit of 4s. 6d. per ton of slack, after paying all expenses in the working of the plant. As this subject is fully dealt with in my papers before the Institution of Civil Engineers (1897) and the Institution of Mechanical Engineers (Dec. 14, 1900) I need say no more about it, but desire, in concluding these remarks, to add my thanks to Mr. Langdon for his most interesting paper and the mass of information it contains.

Mr. Kenny. Mr. T. R. D. KENNY (*communicated*) : It has been suggested by two or three speakers that Mr. Langdon has under-estimated the amount of power required to work his trains by taking as his tractive effort per ton the low figures given by the formula at the foot of Table IV.

I am a little surprised, however, to find that none of those who have had an opportunity of speaking have drawn attention to the fact that Mr. Langdon has provided power for only about two-thirds of the trains, which, according to his figures, must be on the section of line at one time.

His whole estimate is based on the assumption that there are only fourteen trains between London and Bedford requiring power at the

Mr Kenny

same instant; but taking the figures given in columns 4 and 5 of Table IV., it will be seen that there must be about twenty-one trains running at once. The fourteen trains distributed on a fifty-mile section of line could not pass a given station in one hour *unless* the average speed of the trains were *fifty* miles per hour. The express trains *have* this speed, and it is correct to assume that there are only three of these trains on the fifty-mile section when three pass per hour. But take the case of the goods trains with a speed of twenty-five miles per hour. Each train takes two hours to traverse the section, and as five trains pass a given point per hour there must clearly be ten trains on the section at a time.

Taking the other figures in columns 4 and 5 of Table IV. in the same way, we have at any time on the fifty-mile section—

3	Express passenger trains requiring				1,068	kilowatts.
3·12	Ordinary	„	„	„	425	„
5·72	Express goods		„	„	1,257	„
10	Ordinary	„	„	„	1,370	„

giving a total of 21·8 trains, which are taking 4,120 kilowatts at the axles, and—taking Mr. Langdon's over-all efficiency—requiring about 7,000 kilowatts output at the generating station as against 5,000 kilowatts allowed for in the paper.

It has been pointed out in the paper that the conclusions arrived at will not be affected by any small variations in the service, since they are based on "cost per train-mile." At first sight, then, it would seem that the 40 per cent. larger generating station entailed would only affect the magnitude of the undertaking, and be of little consequence. As a matter of fact, however, since the slowly moving trains form a larger percentage of the total on the section than in the original case, a reduction of about 9 per cent. in the figure for "K.W. per train," and of 3 per cent. in "K.W. hours per train-mile" is effected. There should also be a slight saving in the cost per kilowatt-hour due to the increased size of generating station.

These considerations will better to some extent the figure given—7·021d. per train-mile—for the electrical case in Mr. Langdon's interesting paper.

Mr. Seabrook.

Mr. A. H. Seabrook (*communicated*): Mr. Langdon, in his highly important and interesting paper, has shown the many economical advantages that will accompany the employment of electricity upon railways, but it has probably occurred to a good many members that the advantage which will appeal most strongly to the travelling public is that of increased safety.

I refer to the possibility of cutting off current on any section of the line when the signal is against the train. The switches coupling up the distributing cable to the contact rail can be operated by the wire rope that works the signal.

A voltmeter, or some rough form of pressure indicator, connected across the contact and return rails, fixed immediately over each lever in the signal-box, would inform the attendant whether the switches were acting properly or not; the latter an unlikely occurrence, but

Mr. Seabrook.

still to be guarded against. An indicator connected to the neare sections of line controlled by the two neighbouring boxes would aut matically inform the attendant whether his neighbours' sections we clear, whether current was in them, and if so, whether a train was pas ing, shown by the drop on the indicator. Practice only could determi whether the pressure should be kept off the contact rail except whe a train is due; if it were not found advisable, provision could be mac for the lever to work the signal alone, or both signal and switch; but the is no doubt that a great amount of leakage, especially in time of rai and snow, could be avoided. Absolutely to deprive the locomotive c its source of power when the signal is against it seems to me about th most effectual "block" system that could be put into use.

Mr. Varley.

Mr. F. H. VARLEY (*communicated*): In the first place, I feel we ar all much indebted to Mr. Langdon for his very valuable contributio It seems to me that the question is purely a commercial one: Will it b more profitable to use the electric locomotive, and will the railwa companies be justified in replacing their steam locomotives by th new mode of traction? To my mind, everything points in tha direction.

Mr. Langdon deduces a saving of 1·922 pence per train-mile—sa 21·4 per cent. Now we are informed by some of the speakers in thi discussion—It is impossible to improve upon the economies now obtained in the steam locomotive, and it is quite impossible for elec tricity to compete with the present system. I share with most peopl in their admiration of the wonderful amount of applied science and mechanical skill which has improved the pioneer engine designed by Stephenson. The highest engineering mathematician's acumen, along with the mechanical engineer's constructiveness, have been brought to bear and are continually being requisitioned, and we naturally look upon the steam locomotive as a perfect piece of engineering construc tion and design. We are asked to compare this perfect machine with the pioneer electric locomotives, and it is not surprising that the very perfect steam locomotive, the best results of applied technical know ledge and manipulative skill, should not have it all its own way when contesting with the pioneer electric locomotive. The pioneer electric locomotive has come to stay, and will doubtless advance in development in the same way, as experience is gained by practical work. Electric railways, to compete with steam locomotive lines, will have to be worked from a different standpoint—more frequent trains and a reduc tion in the number of carriages per train; because long trains going long distances at long intervals carry very few passengers per train-mile. Hence arises the great waste of power in drawing heavy rolling stock, weighing say 300 to 400 tons per train, out of which not 25 per cent. is the weight of the revenue-earning passengers. In long-distance trains how often is it that they do not carry a full load, or anything like a full load. It is no unusual thing for a train to leave the terminus with 25–50 or even 65 per cent. of its passenger accommodation unoccupied. Now electric traction favours short trains despatched at more frequent intervals, with proportionate decrease of the dead weight of the rolling stock, and a larger percentage of passengers per train,

therefore a larger profit, while securing a greater amount of patronage by the greater facilities offered for travelling. Mr Varley.

A locomotive is undoubtedly a most magnificent monument of human skill, but I defy it to make a profit by drawing hundreds of tons of rolling-stock without any passengers or goods; and yet this is practically done in a greater or less degree by all railways. Take, as one example, early workmen's suburban trains to town, crammed to overcrowding. The total weight of passengers would not exceed 47 to 50 tons; the rest of the load is that of the rolling-stock. The same train returns practically empty, still the heavy draught of the rolling-stock has to be borne by the steam-locomotive. Take the up and down journey of such train together = but 50 per cent. of its passenger accommodation.

Mr. Langdon has fully set forth the economy of stationary as against an itinerant generator. Now electric traction is specially adaptable for working short trains, which means a greater proportion of revenue-earning load to that of the unproductive load of dead weight of rolling-stock, in the dealing of which the electric system must in the long run prove far more economical.

Mr. A. WOODROFFE MANTON (*communicated*): As I have been interested in the design of steam-turbine-driven locomotives, which possess many advantages in common with the modern electric machines, I have been much pleased to have this valuable paper. I would like to draw attention to these special and some other mechanical advantages of the electric "engine" (and its power-house). Mr Manton

(1) It is electrically a combination of 4, 6, or 8 motor-units, the failure of one or two not causing complete, and delaying, breakdown; further, these units may be grouped in series or parallel to meet the resistance and speed conditions. The same alternation can be made with its feeder, the power-house plant. I presume that, later, a large proportion of the gravitation-energy (now *worse than lost*) in descending long or steep gradients will be electrically recoverable in a simple manner, and returnable to the transformer stations, or for use in a motor at the time *absorbing* current.

(2) The power—that is, tractive effort—is not dependent on English load-gauge, on the maximum heating and grate surfaces, wheel diameters, or on the cylinder- and valve-chest room between the frames. The power-house steam cylinders can be efficiently jacketed, while those of the steam locomotive cannot be so assisted. There is an absence of reciprocating parts transmitting large efforts, especially of piston, connecting and eccentric rods, and "side" rods, and a replacement by parts rotating uniformly in constant direction: and the absence of connecting and eccentric rods and crank-webs allows of ample bearing surfaces.

(3) All wheels are drivers and retarders, thus the maximum axle load is much decreased, the total being much lighter for same drawbar-pull; there is, and consequently, less rail-wear (with absence of rail-shock due to want of horizontal and vertical balancing in reciprocating steam practice), greater wheel-base flexibility for high-powered machines, and *no* dependence of adhesion on inefficient "side" rods.

Mr. Manton. (4) The absence of injurious products of combustion will much increase the life, and decrease maintenance, of tunnel rails and the tunnels and bridges themselves.

(5) The greatest possible paying load to be moved on the maximum gradient of a section being independent of loading gauge and rigid wheel-base, the hour tonnage can be readily increased without fear of blocking scheduled traffic, and without resorting to enormous capital increase in acquiring land and widening ways and works.

(6) The moving parts being few with constant direction, shop repairs, renewals and maintenance should be much lessened, especially in labour; all wheel-axle-armature units may be identical and interchangeable in a short time (by electric-lift pit under rails), the difference between locomotives for various duty being made as far as possible in winding and number of axles.

For tunnels, repair-shop roads, and points liable to floods, side overhead trolley contact might be arranged. Undoubtedly much cheaper coal can be converted in the power-house (in absence of gas system even) than with the restricted fire-box locomotive design, and this coal can be more cheaply transported in large *constant* quantities to the fewer points. I think the author has rather, therefore, under-estimated the power-house electromotor economies; and the Italian long-distance installation results will be very interesting (although tonnages will probably be relatively low).

With reference to cost and coal consumption, in one of last year's magazines I noted that the total costs per ton-mile, including staff and repairs, were 0·152d., 0·171d., 0·190d., on the Brooklyn Elevated, average American steam practice, and Manhattan Railway respectively (124, 138, 153 per cent.), against 0·124d. (100 per cent.) on our Liverpool Overhead Railway (electric), which latter is probably hardly now modern practice. Also it was stated that coal consumption ratio on train-mile basis was $\frac{\text{16 electric}}{\text{41 steam}}$; and that the greatest power-house and motor coal consumption per axle per hour was about 79 per cent. of best steam practice. I should be glad if the author could give more modern figures on those points, where it may be said that the traffic and resistance conditions make it comparable.

Mr. Taylor. Mr. A. M. TAYLOR (*communicated*): Though it may be considered by some as undesirable, in a paper of this nature, to criticise details, yet, unless the premises be correct, wrong conclusions may possibly be formed.

First, as to traction resistance. It may be presumed that, in measuring tractive resistance, the locomotive engineer will select as level a piece of the line as possible on which to carry out his tests, so as to avoid corrections due to grades, etc. His principal object is to determine the best performance he can get out of his locomotive in the way of speed, and the coal bill does not concern him to the same extent as it does the electrical engineer, whose principal object is to prove the economy of electric traction. We may then, perhaps, safely assume that losses due to the braking of trains when descending gradients do not enter into the determination of tractive resistance. This matter is,

of course, of less importance on railways than it is on tramways, on which values varying from 0·95 Board of Trade unit per car-mile to 1·7 B.T.U. have been experienced, due to this cause, with the same size of cars. Let us see whether it is a negligible quantity on main-line railways such as we are considering. The average running speed of Mr. Langdon's trains is about 34 miles per hour, and the tractive resistance for the level may be put at 7 lbs. per ton, taking his own figure. So long as the down gradient does not exceed $\frac{1}{320}$ or, say, 16 feet to the mile, it may be considered as compensating the up gradient; but if this limit be much exceeded it will be necessary to apply the brakes. In the route from London to Bedford and back again (100 miles) it is possible that there may be as much as 10 miles of track, in the aggregate, where the gradient exceeds $\frac{1}{160}$, giving a total drop of 320 feet, and 160 feet of this is irrecoverable lost energy. It is true that this would only amount to some 2·5 watt-hours wasted at the generating station for every ton-mile hauled; but if the gradients were much steeper, or longer, than I have assumed, the case would be very different. As it is, it adds nearly 10 per cent. to Mr. Langdon's figure of 26 watt hours per ton-mile for the tractive resistance alone. It would be interesting to know what are the actual conditions on the line in question. Mr. Raworth has given us an estimate of the additional power required for starts and stops (which is, of course, quite independent of that wasted on the gradients), so I do not propose to touch on this loss, which, however, seems to me to be low. Mr. Taylor

Next, as regards the load-factor. Mr. Lackie has referred to the effect of the hourly variations of load on this question. But what I wish to call attention to is that the variations in the output from minute to minute have also no slight effect on the load-factor. The number of trains considered is, comparatively, quite small—only 14—and the fluctuations should be pretty considerable, especially when we remember that goods trains (with their frequent stoppages and starts) form a large proportion of the total weight to be hauled. Taking grades and everything into account, it will be surprising if, for an average load during 24 hours of 5,000 kilowatts, we do not require plant in the station of 8,000 kilowatts, while that of the rotary converters and step-down transformers will be nearly 1,000 kilowatts capacity (excluding spares). Bearing in mind that the efficiency of the engines and of the electrical plant falls off, after a certain point, more rapidly than the output diminishes, we can easily understand that, for an *average* output of 5,000 kilowatts, the all-day efficiencies cannot be sensibly higher than assumed by Mr. Langdon. I think one or two of the speakers seem to have hardly appreciated this point.

Lastly, I wish to say that I quite agree with Mr. Field's reported remarks as to the incorrect number of trains on the line; which do not, however, vitiate those of Mr. Langdon's figures which are based on train-mileage only.

Mr. REGINALD WOOD (*communicated*): The Institution is fortunate in having this important matter brought before it from within the railway companies. Mr. Wood.

The author is to be congratulated on having been content to

Mr. Wood. make only a modest claim in favour of electric traction on the great railways, as no doubt the greater economy will only be achieved when the service takes advantage of the electric supply to alter its method somewhat, and to sell current *en route*.

As I take it the author desires that the discussion should show that his paper has been critically examined, I will mention what appears to me to be an omission in his statement, but as I shall point out a remedy the objection will disappear. It does not appear to me that the author claims all the economy he might in shunting.

The omission is that no mention is made of the kinetic energy of the trains. If every train stops once in a quarter of an hour we have practically one train starting every minute. This would demand an extra 1,000 kilowatts working continuously with a corresponding 20 per cent. increase in the coal bill. There are no data in the paper to enable one to state definitely whether this extra power should be 500 or 1,500 kilowatts. But there is, of course, no doubt that this is a most important matter, though it may be of more importance in suburban traffic. Anyhow, the remedy is to brake the train by returning the energy back to the contact-rails. All that is required is to substitute for the resistance in the series-parallel control a dynamo carried on the locomotive and coupled to another dynamo suitably connected. It gives the incidental advantages of smooth starting and stopping, and the attainment of any electric pressure desired at any point. That is, the electric pressure on the locomotive is under the control of the driver. He can get excess pressure if he wants it. It also gives the advantage of saving the energy usually lost over the resistance and a great part of that lost in transmission.

This is a matter rather more than of mere detail. If there is a serious objection to absorbing the kinetic energy of the train by a brake on the locomotive in front of the train, a good case can be made out for redisposing the motive power. The description of this controller is to be found in Patent Specification 23,854 of 1894. The successful inaugurator of main-line electric supply will have earned a nation's gratitude.

Mr. Merriman. Mr. W. H. MERRIMAN (*communicated*): There is one point which has not been mentioned in the discussion on Mr. Langdon's paper, viz., the extra precautions, impossible on a steam railway, which may be taken to ensure the safety of passengers on an electric railway. A very large percentage of the accidents which from time to time occur on steam railways is due to engine-drivers mistaking the signals or running past them when at "danger." It would be a comparatively simple matter to arrange switches in conjunction with some of the principal signals, each of which would cut out a portion of the contact-rail—say four or five train lengths—beyond the signal whenever it was at "danger." Any driver then running past a signal set against him would have his attention at once called to the fact by the slackening in speed of the train owing to the current being cut off; while, at all events at night time, the guard would also be warned of the danger by the extinction of the train-lights—presuming, as is probable, that these would be supplied with current taken direct from the contact-rail. It would, of

course, be necessary to provide against the possibility of a switch being opened before a train had reached the end of that section of the contact-rail which it controlled, in the event of the signal being raised immediately after the train had passed; but this, I think, would offer but few practical difficulties. Mr Merriman.

Mr. J. Brown (*communicated*): I observe that engineers have recently been turning their thoughts towards the contriving of some means to avoid the delay involved in stopping "local" trains at all the stations, though only a fraction of the passengers wish to enter or alight at any one station. The plan of which I send a sketch avoids this inconvenience, provides a through train for every passenger from any station to any other, and dispels all anxiety or doubt about alighting at a wrong station or being carried past the right one. As my scheme could be worked best by electric motors, and as steam locomotives would be quite inapplicable, it falls not inappropriately within the scope of the present discussion. Mr Brown.

The sketch (Fig. B) is intended to represent an endless railway with coaches arranged ready for starting the day's work. The coaches are

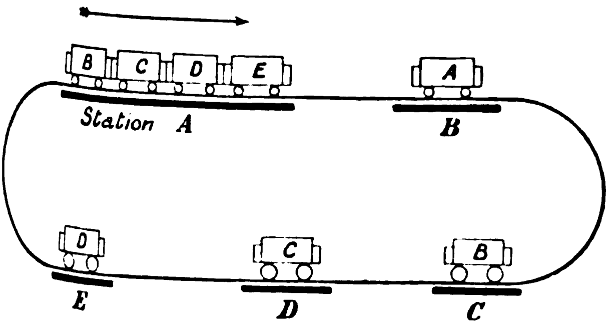

Fig. B.

of the corridor type or like American vestibule cars, so as to give a passage right through the train. Each coach has its own separate motor, and can thus run independently. A train consisting of, say, four coaches, starts from station A. As this train approaches station B, the coach A standing there is started by the driver in charge of it, and sufficient speed given to it to allow it to be picked up between stations B and C by the following train. This may seem difficult, but in reality there should be no more difficulty in picking up a coach in steady motion than there is every day in running gently up to one at rest. It is merely a question of relative motion, and with electric motors the speed would be easily and quickly controlled. If necessary, an appropriately placed signal-box would eliminate any possible risk at this point. As soon as coach A has been picked up, the driver of the train goes to its forward end and there takes control of the train, connection being made to all the other carriage motors for that purpose; or the driver of coach A takes charge of the train, and the former driver goes to the rear coach ready to slip it.

Mr. Lawson. much too low an efficiency in his motors and in his method of transmission throughout. For instance, he has taken the motors with 85 per cent. efficiency; the ohmic loss in transmission at 10 per cent.; leakage $2\frac{1}{2}$ per cent.; loss in rotary converters 10 per cent.; in static transformers 7 per cent., and in high-tension transmission 10 per cent. I think he might very well have assumed that he could get nearly 90 per cent. in motors; a line loss of 5 per cent., even assuming that he has his insulation resistance as low as Mr. Walton put it. He could get 97 per cent. efficiency in his static transformers instead of 93; 93 per cent. in his high-tension transmission instead of 90; and 71·35 per cent. over-all efficiency instead of the 58 per cent. he assumes. If, however, he adopted a three-phase transmission, eliminating altogether his rotary converters, and taking his own efficiencies, he could still obtain 62 per cent. instead of 58; this gain may not be very great, but it is an addition of $4\frac{1}{2}$ per cent. In taking the efficiencies I have assumed, he could get 75 per cent. over-all, which will go very far towards reducing the coal bills that I am rather surprised the apostles of electric traction in this assembly are so very desirous of putting up. I cannot understand their object. Is it that they are not ready to meet the case of electrical equipment of main lines of railway? It has been done on the Continent. As Mr. Swinton has mentioned, high-tension, three-phase transmission has been in fairly successful use on the Burgdorf-Thun Railway, and a higher voltage, four times as much as on the Burgdorf-Thun line, is going to be put into use on another line next month, I hope. We shall then gain some information which will be useful, and although the station is a water-power station, I think it will dispose to a very large extent of the suggestion of separate stations at intervals of every five miles. Not only will they save the attendance which Mr. Langdon has estimated for at every one of his sub-stations, but with generating stations, as Mr. Robinson suggested, for every ten miles (which, as Mr. Swinton has justly pointed out, will mean a station loaded for a few moments and unloaded for the greater part of the hour) there will be a coal consumption in excess of the figures which have been mentioned by Mr. Walton and others. With a station every ten miles or so you might just as well retain the present locomotives—indeed, I think it would be better to do so, because you would otherwise have the assistants not only on the locomotives but at the sub-stations increased in number.

Mr. Siemens. Mr. A. SIEMENS: I would like to draw the attention of the meeting to the fact that the title of the paper is "The Supersession of the Steam by the Electric Locomotive," while the discussion has now entirely branched off into a statement of the fact that where a line of railway has eleven or twelve trains per hour, it is cheaper to run it electrically than by steam. That, I think, we all know. As Professor Forbes has already pointed out, that does not want proving. Mr. Langdon can afford to give the £330,000 for his conductors, which I think is the proper figure, and he can afford to wipe off the coal saving, which does not exist according to my idea, and still he will show a saving on such a line. But he proposes in his paper that the

Midland Railway Company, for instance, should go on converting its line gradually fifty miles by fifty miles. Is he going to stop his Scotch expresses at Bedford to change engines when he has completed the first stage? What also is he going to do on those portions of the Midland line where there are very few trains—only two or three per hour? I think what Mr. George Westinghouse said a year ago is still absolutely true, that for suburban traffic, for any traffic which has something like ten or twelve trains an hour and upwards, it is natural that electric traction will come and that electric traction is the proper thing; but for the long main-line trains, for those parts of the railway system where there are only a few trains per hour, I do not think there is any chance yet of introducing an economical system of electric traction. Mr. Siemens

Major P. CARDEW: I think Mr. Walton and Mr. Hudlestone possibly have been misled as regards this column in Table IV., Mechanical Horse-power per Train Hour. Major Cardew.

Mr. LANGDON: What I was desirous of expressing was the fact that that power was required for an hour. The table seeks to reduce everything to an hour's work, and therefore the horse-power is not intended to express exactly what is the maximum horse-power being used at any time in kilowatt-hours. Mr. Langdon.

Major CARDEW: I think that one important thing to notice in the tables given in the paper is the extremely small number of miles over which each locomotive is run in the week. I find from them that on the North-Western Railway they only use each locomotive for 314 train-miles per week. Taking into consideration the time of the drivers and the firemen, the wages table comes out enormously high, and I do think a considerable economy is possible with electrical traction. Apart from the possibilities of absolutely reducing the employés on a train (which, I think, is quite within contemplation, seeing that the work to be done is reduced to practically nothing), there is much time lost by the steam locomotive before starting and after returning to the shed and during the time it is taking in water and coal. I find that in most railways they allow three-quarters of an hour for the driver and fireman before starting, and the same time after the engine has returned to the shed. All these little items mount up. Major Cardew.

Mr. Langdon deals with the traffic as it exists. If it were really in contemplation to equip a line electrically, no doubt it would be possible to find out how the service could be best suited to the new means of working, and the tendency would be to run shorter and more frequent trains. Then, with regard to the terminal stations. With motor-cars at each end of the train, it would be possible to clear the train out of the station in very much quicker time than it takes to shunt an ordinary train with a locomotive. Much could thus be saved. In the same way the goods traffic could be arranged on much better lines for electrical working. I find that a great deal of use is now being made on the Continent of locomotives with accumulators for shunting purposes, and of course they fulfil a very desirable object. In shunting, neither power nor speed is required, but only a good horse, as it were, to drag the trucks about, and an accumulator locomotive does the job and saves a great deal of expense in the equipment of sidings. I may

Major Cardew.

say that I have seen the experimental line at Buda Pesth and closely studied it, and am quite satisfied with the working. The working is admirable, and by the arrangement of the three-phase motors in series, whereby they tend to halve the speed, a great economy is effected in the starting. The same thing comes into operation in the stopping; the other motor is switched in in series, and the immediate effect is the return of power to the line. In that way the three-phase working certainly has an enormous advantage over the ordinary continuous-current system.

Mr. de Segundo.

Mr. Ed. C. de Segundo: The author has attacked a subject which, in my judgment, is destined in the near future to be one of national importance, and I trust that he will accept my assurance that any remarks I may have to make on his figures are made with due deference to the opinions of one so much my senior in age and experience. First with regard to the important subject of coal consumption, Mr. Langdon has put down the figure of 3 pounds per kilowatt-hour. I have looked up some figures, and find that the consumption of coal per kilowatt-hour at the Central Station of the Dublin Railways works out to 2·1 pounds on the basis of the boilers evaporating 8 pounds per pound of coal. At the Dortmund Electricity Works it is 2·8 pounds per kilowatt generated; on the Berlin tramways it is 2·3 when using saturated steam, and with superheated steam 2·1. It must be remembered that these are test figures. I have worked out the average consumption of coal per kilowatt-hour distributed on seven of the more important central stations on the Continent, including Berlin, and I find that it works out at 4·5 pounds. This seems to point to the fact of Mr. Langdon's allowance of 3 pounds being somewhat narrow; but on the other hand one has yet to be quite sure what the load-factor will be in the circumstances in which Mr. Langdon's figures are conceived—the application of electric traction to a railway.

So far, the application of electric traction has been made under conditions which, so to speak, have been in favour of electricity—that is to say, the railway has been built for an electric railway, and there is not a sufficiently extended record of the performance of electric locomotives doing railway work under the conditions which obtain in any ordinary main line, so that we can only hazard a guess as to the nature of the load-factor which will obtain in those circumstances. Mr. Langdon has not suggested how freight-traffic is to be dealt with, and through-traffic is also an important point. Both of these contribute very largely to revenue: in fact, the revenue from freight-traffic may be 2½ times or 3 times that which is obtained from passenger-traffic, and the through-traffic may be from 45 to 50 per cent. of the whole traffic of the line. While the tendency is more and more towards short, frequent, and consequently light trains for passenger-traffic, which is admirably suited to electric traction conditions, the tendency is to increase the length, and consequently the weight, of freight-trains and to run them at longer intervals. Of course from a steam railway point of view the economic aspect of this is apparent on the face of it. But, with electric traction, it is obvious that the frequent starting of these heavy freight-trains would be a factor operating disadvantage-

ously to the economy of the steam engine at the generating station. On the other hand, there is one point in favour of electricity I do not think anybody has referred to yet, and it is a very important one. We all know that only about half of the total weight of the locomotive and tender is available for tractive purposes; in the electric locomotive it is possible to apply the whole weight on the driving axles. Therefore the conclusion will be obvious that for a given tractive effort an electric locomotive need only be half the weight of a steam locomotive; and I need hardly point out the reduction in the wear and tear of the permanent way, and the consequent saving of expense of the cost of maintenance, that would result from that alone. The total absence in electric traction of "pounding," which it is impossible to avoid in the steam-locomotive, due to unbalanced piston-effort, would operate largely towards a reduction in the cost of maintenance of the permanent way. With regard to this complex question of large or small stations, I merely throw out the suggestion that should such an event be contemplated as the supersession of all steam locomotives on a line like the Midland by electric locomotives, it might be possible for the electric generating stations in some of the big cities and towns through which the railway passes to contribute in some measure to the current necessary for traffic purposes. This does not remove the objections I have raised before; but it is a possible means of reducing the capital expenditure of a railway company which contemplates such a step by making use of existing sources of supply. Mr. de Segundo.

With reference to the financial aspect of the question; during recent visits to the United States I have on every occasion been struck by the fact that our American cousins seem to have anticipated the fact that the future is pregnant with big events, and they have made preparations to cope with any demand that may arise. We in England have not kept pace with the times, and if we are to recover our position—I use the word advisedly—we should tear from our eyes the veil of pride and prejudice which prevents us realising our own deficiencies, and consent to learn from our neighbours, notably the United States, so that we can regain the trade we have lost, and re-establish our position of commercial supremacy amongst the nations of the world.

Mr. FRANK SPRAGUE: I have not had the time to criticise this paper, and I prefer not to do so. In considering any electric railway proposition, the practical question always stares me in the face: How is one to accomplish a result, and is it worth the while? Being possibly somewhat of an enthusiast on matters of electric traction, having given a number of years to the subject, there is no attempted solution of problems of this character, whether concerning suburban or main-line service, that does not command my interest, and I always welcome the various proposals made. Mr. Sprague.

I think the statement can be very safely made that electric railways will not be conducted on steam lines. The question is not the supersession of the steam-locomotive by the electric. The electric locomotive, rated as the steam-locomotive is rated, hardly exists. If a dynamo is considered, we wish to know the continuous output of which it is

Mr Sprague. capable, and you gentlemen who are consulting engineers prescribe very rigid conditions of test. It must run for so many hours, at a certain speed, and a certain output; it shall have a certain capacity of excess, and so on. In short, the machine must be of permanent character, built for years of continuous service. With a stationary motor, similar requirements exist. It must be a machine which, hour after hour, shall be able to deliver a certain horse-power. On the contrary, whether it be because of a misconception of what electric railways demand, or because actuated by a somewhat unnecessary commercial instinct, the manufacturers of electric railway-motors have adopted a unique method of rating. For example, we hear of motors of 50, 75, and 150 H.P., the latter being probably amongst the largest of the units which are regularly built for railway service. These ratings mean little except that, for example, a 100 H.P. motor, railway-standard, can for an hour do 100 H.P. of work, and can stand a 50 per cent. excess of load for another ten minutes, but that is not, properly speaking, the rating of a railway-motor, as has been shown in a very interesting manner by Mr. John Lundie, who has made a special study of the kinetics and requirements of heavy electric traction.

Common sense teaches us that if the electric motor is put against the steam-locomotive, it must be a machine capable of equal continued service, and it should be rated in a general way the same as any other electric machine, on its average, as well as its special, capacity. If a small railway-motor is rated in a certain way by the hour-basis, a larger one tested under the same conditions has a fictitious and excess rating compared with the smaller one. Speaking generally, any steam or electric railway-motor should have as a measure of its rating what it can do hour after hour on active service.

Looking at Table IV., there seems to me to be a rather curious series of figures, and I quite agree with Mr. Hudleston that they are underestimated in the matter of actual H.P. required. The method of determining train-miles per hour by multiplying the trains passing a given point by the running speed is erroneous.

What is an electric locomotive? It is simply an assemblage in which is localised a multiplicity of motors, generally four motors on four drivers, the motors being built to fit spaces which, because of the conditions under which the motor has to be operated, are restricted by wheel dimensions, wheel base, track gauge, distance between wheel seats, transom and axle, and there is a very definite limitation to the size of a motor so determined. To illustrate this fact, take, for example, one of the largest types of motors now built, rated at 160 H.P. For continuous service, and with an excess of temperature of say 75° C. above the surrounding atmosphere, it can stand about 35 kilowatts of continuous average input, or develop an average of, say, 40 H.P. available for effective traction.

I think that it is safe to say that the electric locomotive will not generally take the place of the steam-locomotive. If a steam-railway adopts electric traction, it must radically change its service; it must adopt smaller train-units, complete within themselves, operated independently, or in combinations making up longer trains. Then one

must do what is done with a hand-controlled locomotive, use a multiplicity of motors, but a greater number, distributed on the different cars or motor-car units. As soon, however, as this condition is determined, direct hand-control must be wholly or partly abandoned for general work, and the motor equipments put under a secondary control. We have to face the very practical fact that we cannot, without unnecessary restriction, compress upon a single unit the power that is necessary to do the service that is done by a steam-locomotive to-day. I of course do not agree with the last speaker that an electric motor can be built of half the weight of the steam-locomotive, that is if it is to do equal service; but it is perfectly possible—and it is being done every day—to consolidate any number of units equipped with any required amount of power, under a common control. Mr. Sprague.

It is not sufficient reason for adopting electric traction to say that you can save some coal, for in many instances, especially with long trains, I question whether you can save a dollar's worth. The question of coal is a secondary one. What is all-important is capacity for increased speed, and the making of train-lengths and train-intervals subject to the will of the train-manager—in short, the ability to get and to accommodate traffic and service. I repeat that the electric locomotive on a trunk-line service has not a promising future. That service itself must be changed with change of motive power. The question reduces itself simply to the number of units which are in operation between two points. If the units are few in number, electric application is not generally to be considered. As the number increases sufficiently, then there will be a field for electric application, and then only.

Professor C. A. CARUS-WILSON: There are, in my opinion, three reasons why the supersession of steam by electricity on the railways of this country will take place first, not on the main lines, but on the branch lines. Prof. Carus-Wilson.

In the first place, the branch lines, or, to be more specific, the cross-country lines, as distinguished from the main lines, are the least profitable part of any great railway system. And since it is the wisdom of economic railway management to ascertain what is the least profitable part of the system, and make it, if possible, more profitable, it will always be to the interest of the great railway companies to endeavour to make the branch lines pay better, in comparison with the main lines, than they do now.

A few figures will show that the branch lines are, as a rule, far less profitable than the main lines. Taking the Board of Trade Returns for 1899, we find that for the Midland Railway the average profit per passenger train-mile is about tenpence. Taking the average number of trains per day, each way, on branch lines, as six, the profits from the passenger service per mile per day is five shillings. On a main line, on the other hand, the number of passenger trains each day might be taken at thirty each way, making the profit per mile each way twenty-five shillings, five times that of the branch lines. No doubt this is a rough estimate, but it is probably not far from the truth. Hence in considering the possible economy to be effected by the introduction of elec-

Prof. Carus-Wilson.

tricity, it will be more to the interest of the companies to endeavour to make their branch lines more profitable, than to make changes on their main lines, which are at present relatively very remunerative.

The second reason I would give for cross-country lines being dealt with first is that the cross-country lines are mainly responsible for the unpunctuality which is such a feature of our railways. I cannot attempt to establish this statement fully here to-night, but may put it briefly thus. The limited traffic on the cross-country lines does not admit the provision of a staff adequate to deal with the traffic. If the traffic were spread out over the whole working day the staff would be sufficient, but it comes all with a rush at infrequent intervals, the result being delay and unpunctuality, especially during the holiday seasons.

The infrequent service and the unpunctuality on branch lines has made cross-country travelling most unpopular, with the result that these lines are now being menaced by the tramway systems which are being projected in all parts of the country. This is a third and most powerful reason why railway managers will be obliged to consider seriously the possibilities of electricity on branch lines.

The remedy for the unpunctuality and the unpopularity of the branch lines is to be found in a more frequent service. To make proper connections with the main-line trains the service on the branch lines should be increased from an average of six trains each way per day to at least twenty-four—that is, a half-hour service instead of a train every two hours. The question is, can this be done by electricity at a profit?

To answer this question, we must know how much each mile of line contributes as profit, from its passenger service, to the general revenues of the railway, and also how much each mile must earn in order to pay its share of the fixed charges, such as maintenance of permanent way, etc. We shall probably not be far wrong in taking five shillings per day-mile as profit, and eleven shillings per day-mile as the contribution towards the fixed charges on a branch line with six trains each way per day. If, now, the running cost per passenger train-mile, that is, the locomotive charges and the guard's wages, be put at elevenpence, a traffic equal to 264 third-class passengers will be required per day-mile each way. We may, then, take this to be the traffic on a branch line as at present run by steam.

For a service of twenty-four trains per day the fixed charges and the profit per day-mile will remain the same, if the branch is to yield no more and no less profit than before, but the running charges will increase in proportion to the number of trains, and for twenty-four trains will require an income of 24×11, or 264 pence per day-mile, which, added to the fixed charge, makes 462 as the required number of third-class passengers per day-mile—that is, an increase of 75 per cent. in the traffic as compared with that required for six trains per day. The traffic must exceed this if the altered conditions of working are to yield an increased profit per mile.

Now the whole difference introduced by electrically driven trains is that the running charges are less. If motor-cars with substantial trailers are used, as on the Burgdorf-Thun line, weighing, say 50 tons,

with only a conductor and motor-man, the running charges should not exceed sixpence per train-mile. Taking this figure, we find that the number of third-class passengers required to yield the same profit and fixed-charge income per day-mile as before is 342, or an increase of 30 per cent. over the existing six-train service. Now a service of twenty-four trains each way per day might safely be relied upon to induce an increase of traffic of 30 per cent. over that of a six-train service. Anything beyond this will increase the profit per mile; thus an increase of 52 per cent. in the traffic would double the profit on the line, and an increase of 75 per cent., which with steam-driven trains would not augment the profit at all, would result in a trebling of the profits. Prof. Carus Wilson.

The right course, then, seems to be to begin on the branch lines first, to break up the system of infrequent and heavy trains hauled by steam locomotives, and substitute lighter trains running at least four times as frequently, driven by electric motor-cars. The increased traffic would be handled with far greater ease than the existing traffic,

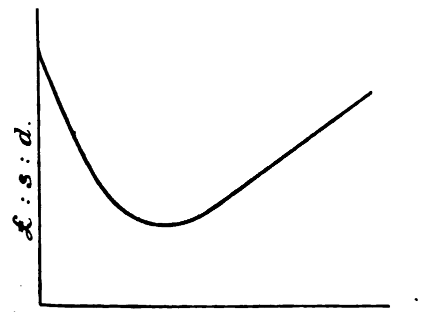

FIG. A.

because it would be more distributed over the whole day. The service would be punctual and popular, and with these advantages there is little reason to doubt that it would be profitable.

Mr. A. P. TROTTER (*communicated*): Mr. Langdon has treated the problem on broad lines, and has not obscured it by detailed consideration of special points. It is quite sufficient for his purpose to assume five sub-stations, without proving that this number is better than four or six. Since he does not give data from which such proof might be established, and since I have no such data at hand, I do not propose to criticise his assumption, but to make some general observations on this point. Mr. Trotter.

If the number of sub-stations on a fifty-mile line be increased, the first cost and sub-station labour cost will be increased, the load-factor of each will be smaller, and the ohmic loss in high-pressure feeders is increased, but the much more important loss in the working conductor is reduced, and this conductor might be reduced in size and cost; and the pressure is more uniform. If the number of sub-stations be reduced, the first cost and sub-station labour cost is reduced, the load-factor will

Mr. Trotter. be greater, while the ohmic loss is increased up to the limit when no sub-stations are used. The working conductor would have to be increased to avoid excessive fall of pressure, but this case can hardly be said to have even that indifferent kind of interest known as academic. All of the factors have a monetary value, except the variation of pressure to which no such value can be easily assigned. That uniformity of pressure is important in some cases is proved by the large number of sub-stations on the Burgdorf-Thun line, but these are inexpensive and require no labour.

Given the necessary data, the conditions for minimum total cost (capital and working) may be calculated. Differential calculus will show the exact number, which is of little interest and no use. Plotting a few examples on a curve (Fig. A) will show whether the curve has a sharp or a flat bottom. It will probably be found that the bottom is flat enough to allow several external considerations, such as choice of site and neighbouring gradients, to influence the decision on the number of sub-stations.

It is probable that the number of sub-stations indicated by the mere question of cost will yield a sufficiently uniform working pressure. In tramway work the uniformity of pressure generally takes care of itself, and is the outcome of other conditions. But such conditions may perhaps show that a uniform working pressure is difficult to attain in railway work. It is said that for three-phase motors no large reduction of working pressure is safe, but for continuous current, considerations of economy and of speed allow no little latitude. It is obvious that it does not pay to level a railway through undulating country, gradients are inevitable, and they control the speed. How far will it pay to level the working pressure? If economy demands widely spaced sub-stations, variation of pressure on the working conductor and consequent variation of speed may be a feature of the railway practice of the future. There is a good deal of difference between the maximum safe speed and the economically best speed on a well-built line. It may be an economy to space sub-stations more widely on level country, and, with suitably designed motors, to allow much larger variations of working pressure than are to be found in modern tramway practice.

Mr. Tyler. Mr. E. H. Tyler (*communicated*): I beg to share Mr. Hudleston's opinion that the electrification of main railway lines is not at present a promising field of electrical development. In any case the suburban and cross-country lines have an overwhelming claim to be treated first. But there are objections to such a sweeping change as the electrical equipment of our main lines which, I believe, have not yet been mentioned. In most European countries the railways, if not actually Government property, are under their close control, it being recognised that railways are part of the national scheme of defence.

It will not, I suppose, be pretended that an electrically equipped line is not more liable to be disabled than a steam line. The characteristic of the breakdown of a system supplied from a central source of energy is general paralysis as distinct from local injury.

There are many main lines in England that are subject to floods,

and it is obvious that it would be easier to throw an electric railway out of gear than a steam line. Mr. Tyler.

These serious considerations, as well as there being no really pressing necessity for the change, lead me to believe that the electrical equipment of our main lines is not yet within sight. The frequent reference to the Burgdorf-Thun railway as an example of main-line electrical traction is misleading. It is a full-gauge passenger and goods line, but in no sense is it a main line such as the Midland or Great Western.

Major Cardew's account of the three-phase line at Buda-Pesth was most interesting, especially his reference to the placing of the motors in series at starting and during retardation. It is not easy to see how this arrangement can return current to the line, inasmuch as the energy returned must be of the same periodicity as the line. But in any case the return of energy can only be carried down to half speed, whereas with continuous currents the regeneration can be continued until the train has nearly come to a stop.

As regards Mr. Sprague's remarks on locomotives, it is, as he points out, almost entirely overlooked that the power that can be exerted on the axles of a locomotive is strictly limited by the dimensions of the gauge and the permissible length of the wheel base. The claim of Mr. Sprague's multiple unit system is that a train composed of traction units shall have the same tractive characteristics as a single unit. Applying this test to railway trains, I would ask Mr. Sprague what he considers a railway unit to be. Obviously not one coach. If we take one half of an ordinary train to be a railway unit, and provide a locomotive of suitable weight and power to draw that unit, it follows that a full train of two units can be drawn by two locomotives coupled and controlled as one, with the same characteristics of speed and torque as the single-unit train. That appears to me to be the true solution of the principle of multiple unit control, rather than the multiplication of motor coaches. It cannot be forgotten that the adoption of motor coaches entails a wholesale scrapping of rolling stock which no company will care to face. Moreover, for many years the service on electrical lines must necessarily be a mixed one, or at all events through traffic will have to be provided for. The electrical locomotive, although not an ideal application, seems therefore to be a necessity.

Mr. H. A. HUMPHREY (*communicated*): It is admitted that the supersession of the steam by the electric locomotive is primarily one of costs. Table V. giving the cost of generation and distribution of current, is therefore of vital importance, and should have received special care; yet I regret to find it is the most disappointing part of the paper. Mr. Humphrey.

The first inspection of the table would lead one to say that the cost of generating a kilowatt-hour had been taken at 0·1574d. This, however, is not so, for the cost of oil, waste, and sundries is placed at the bottom of the page, and is not included in the total along with coal and water, although the one is as necessary to the engines as the others. Then there is no item for repairs and maintenance of the generating plant included in the table, and in seeking for this important item we

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Mr. Humphrey.

find that no definite figure is anywhere given, but it is dealt with along with the locomotive charges.

As a matter of fact Mr. Langdon's figures for the cost of energy from a steam-driven central station cannot be considered as constituting a safe basis for calculation. I have studied the question in this country, on the Continent, and in America, and have obtained figures at first hand from the chief engineers of large American traction stations. As a result I entirely endorse Mr. Cunningham's statement that 0·25d. per kilowatt-hour is the limit at present practically attainable in a steam-driven plant. In the case of one of the largest electrolytic plants in this country with the best modern engines and boilers and cheap coal, this figure was not quite reached even with 100 per cent. load-factor and in a year of cheap coal. The figures for the year in question were given to me by the engineer, and included no fixed charges. One of the most reliable statements of costs I know of is that given by Mr. R. W. Conant in his paper on "Cost of Electric Power for Street Railways," read before the "America Street Railway Association" in September, 1898. Mr. Conant examines and tabulates the costs from forty-four of the large traction stations in America, and he found the lowest operating cost per kilowatt-hour at the switchboard was 0·52 cents. (0·26d.). Mr. Conant describes a "standard station," and gives a standard set of figures as being the best practical. These figures come out at 0·58 cents. for operating cost and 0·405 cents. for fixed charges, making a total of 0·985 cents. (0·49d.). The load-factor is taken at $33\frac{1}{3}$ per cent., and the following statement is made :—"As this station is described its performance may seem to border on the ideal, and there is no question but that its performance is consequent on favourable circumstances, very nearly, we may say, test conditions."

To reach figures much below these a radical change is necessary, and as one attempt at the solution of the problem I would direct attention to the use of large gas-engines and Mond gas-producers. The Mond plant employs cheap bituminous slack, and recovers the ammonia in such large quantities as to allow a profit of 4s. 6d. per ton of slack, after paying all expenses in the working of the plant. As this subject is fully dealt with in my papers before the Institution of Civil Engineers (1897) and the Institution of Mechanical Engineers (Dec. 14, 1900) I need say no more about it, but desire, in concluding these remarks, to add my thanks to Mr. Langdon for his most interesting paper and the mass of information it contains.

Mr. Kenny.

Mr. T. R. D. KENNY (*communicated*) : It has been suggested by two or three speakers that Mr. Langdon has under-estimated the amount of power required to work his trains by taking as his tractive effort per ton the low figures given by the formula at the foot of Table IV.

I am a little surprised, however, to find that none of those who have had an opportunity of speaking have drawn attention to the fact that Mr. Langdon has provided power for only about two-thirds of the trains, which, according to his figures, must be on the section of line at one time.

His whole estimate is based on the assumption that there are only fourteen trains between London and Bedford requiring power at the

same instant; but taking the figures given in columns 4 and 5 of Table IV., it will be seen that there must be about twenty-one trains running at once. The fourteen trains distributed on a fifty-mile section of line could not pass a given station in one hour *unless* the average speed of the trains were *fifty* miles per hour. The express trains *have* this speed, and it is correct to assume that there are only three of these trains on the fifty-mile section when three pass per hour. But take the case of the goods trains with a speed of twenty-five miles per hour. Each train takes two hours to traverse the section, and as five trains pass a given point per hour there must clearly be ten trains on the section at a time. Mr. Kenny.

Taking the other figures in columns 4 and 5 of Table IV. in the same way, we have at any time on the fifty-mile section—

3	Express passenger trains requiring	1,068	kilowatts.
3·12	Ordinary " " "	425	"
5·72	Express goods " "	1,257	"
10	Ordinary " " "	1,370	"

giving a total of 21·8 trains, which are taking 4,120 kilowatts at the axles, and—taking Mr. Langdon's over-all efficiency—requiring about 7,000 kilowatts output at the generating station as against 5,000 kilowatts allowed for in the paper.

It has been pointed out in the paper that the conclusions arrived at will not be affected by any small variations in the service, since they are based on "cost per train-mile." At first sight, then, it would seem that the 40 per cent. larger generating station entailed would only affect the magnitude of the undertaking, and be of little consequence. As a matter of fact, however, since the slowly moving trains form a larger percentage of the total on the section than in the original case, a reduction of about 9 per cent. in the figure for "K.W. per train," and of 3 per cent. in "K.W. hours per train-mile" is effected. There should also be a slight saving in the cost per kilowatt-hour due to the increased size of generating station.

These considerations will better to some extent the figure given—7·021d. per train-mile—for the electrical case in Mr. Langdon's interesting paper.

Mr. A. H. SEABROOK (*communicated*): Mr. Langdon, in his highly important and interesting paper, has shown the many economical advantages that will accompany the employment of electricity upon railways, but it has probably occurred to a good many members that the advantage which will appeal most strongly to the travelling public is that of increased safety. Mr. Seabrook.

I refer to the possibility of cutting off current on any section of the line when the signal is against the train. The switches coupling up the distributing cable to the contact rail can be operated by the wire rope that works the signal.

A voltmeter, or some rough form of pressure indicator, connected across the contact and return rails, fixed immediately over each lever in the signal-box, would inform the attendant whether the switches were acting properly or not; the latter an unlikely occurrence, but

Mr. Seabrook. still to be guarded against. An indicator connected to the nearest sections of line controlled by the two neighbouring boxes would automatically inform the attendant whether his neighbours' sections were clear, whether current was in them, and if so, whether a train was passing, shown by the drop on the indicator. Practice only could determine whether the pressure should be kept off the contact rail except when a train is due; if it were not found advisable, provision could be made for the lever to work the signal alone, or both signal and switch; but there is no doubt that a great amount of leakage, especially in time of rain and snow, could be avoided. Absolutely to deprive the locomotive of its source of power when the signal is against it seems to me about the most effectual "block" system that could be put into use.

Mr. Varley. Mr. F. H. VARLEY (*communicated*): In the first place, I feel we are all much indebted to Mr. Langdon for his very valuable contribution. It seems to me that the question is purely a commercial one: Will it be more profitable to use the electric locomotive, and will the railway companies be justified in replacing their steam locomotives by the new mode of traction? To my mind, everything points in that direction.

Mr. Langdon deduces a saving of 1·922 pence per train-mile—say 21·4 per cent. Now we are informed by some of the speakers in this discussion—It is impossible to improve upon the economies now obtained in the steam locomotive, and it is quite impossible for electricity to compete with the present system. I share with most people in their admiration of the wonderful amount of applied science and mechanical skill which has improved the pioneer engine designed by Stephenson. The highest engineering mathematician's acumen, along with the mechanical engineer's constructiveness, have been brought to bear and are continually being requisitioned, and we naturally look upon the steam locomotive as a perfect piece of engineering construction and design. We are asked to compare this perfect machine with the pioneer electric locomotives, and it is not surprising that the very perfect steam locomotive, the best results of applied technical knowledge and manipulative skill, should not have it all its own way when contesting with the pioneer electric locomotive. The pioneer electric locomotive has come to stay, and will doubtless advance in development in the same way, as experience is gained by practical work. Electric railways, to compete with steam locomotive lines, will have to be worked from a different standpoint—more frequent trains and a reduction in the number of carriages per train; because long trains going long distances at long intervals carry very few passengers per train-mile. Hence arises the great waste of power in drawing heavy rolling stock, weighing say 300 to 400 tons per train, out of which not 25 per cent. is the weight of the revenue-earning passengers. In long-distance trains how often is it that they do not carry a full load, or anything like a full load. It is no unusual thing for a train to leave the terminus with 25–50 or even 65 per cent. of its passenger accommodation unoccupied. Now electric traction favours short trains despatched at more frequent intervals, with proportionate decrease of the dead weight of the rolling stock, and a larger percentage of passengers per train,

therefore a larger profit, while securing a greater amount of patronage by the greater facilities offered for travelling. Mr. Varley.

A locomotive is undoubtedly a most magnificent monument of human skill, but I defy it to make a profit by drawing hundreds of tons of rolling-stock without any passengers or goods; and yet this is practically done in a greater or less degree by all railways. Take, as one example, early workmen's suburban trains to town, crammed to overcrowding. The total weight of passengers would not exceed 47 to 50 tons; the rest of the load is that of the rolling-stock. The same train returns practically empty, still the heavy draught of the rolling-stock has to be borne by the steam-locomotive. Take the up and down journey of such train together = but 50 per cent. of its passenger accommodation.

Mr. Langdon has fully set forth the economy of stationary as against an itinerant generator. Now electric traction is specially adaptable for working short trains, which means a greater proportion of revenue-earning load to that of the unproductive load of dead weight of rolling-stock, in the dealing of which the electric system must in the long run prove far more economical.

Mr. A. Woodroffe Manton (*communicated*): As I have been interested in the design of steam-turbine-driven locomotives, which possess many advantages in common with the modern electric machines, I have been much pleased to have this valuable paper. I would like to draw attention to these special and some other mechanical advantages of the electric "engine" (and its power-house). Mr. Manton

(1) It is electrically a combination of 4, 6, or 8 motor-units, the failure of one or two not causing complete, and delaying, breakdown; further, these units may be grouped in series or parallel to meet the resistance and speed conditions. The same alternation can be made with its feeder, the power-house plant. I presume that, later, a large proportion of the gravitation-energy (now *worse than lost*) in descending long or steep gradients will be electrically recoverable in a simple manner, and returnable to the transformer stations, or for use in a motor at the time *absorbing* current.

(2) The power—that is, tractive effort—is not dependent on English load-gauge, on the maximum heating and grate surfaces, wheel diameters, or on the cylinder- and valve-chest room between the frames. The power-house steam cylinders can be efficiently jacketed, while those of the steam locomotive cannot be so assisted. There is an absence of reciprocating parts transmitting large efforts, especially of piston, connecting and eccentric rods, and "side" rods, and a replacement by parts rotating uniformly in constant direction: and the absence of connecting and eccentric rods and crank-webs allows of ample bearing surfaces.

(3) All wheels are drivers and retarders, thus the maximum axle load is much decreased, the total being much lighter for same drawbar-pull; there is, and consequently, less rail-wear (with absence of rail-shock due to want of horizontal and vertical balancing in reciprocating steam practice), greater wheel-base flexibility for high-powered machines, and *no* dependence of adhesion on inefficient "side" rods.

Mr. Manton. (4) The absence of injurious products of combustion will much increase the life, and decrease maintenance, of tunnel rails and the tunnels and bridges themselves.

(5) The greatest possible paying load to be moved on the maximum gradient of a section being independent of loading gauge and rigid wheel-base, the hour tonnage can be readily increased without fear of blocking scheduled traffic, and without resorting to enormous capital increase in acquiring land and widening ways and works.

(6) The moving parts being few with constant direction, shop repairs, renewals and maintenance should be much lessened, especially in labour; all wheel-axle-armature units may be identical and interchangeable in a short time (by electric-lift pit under rails), the difference between locomotives for various duty being made as far as possible in winding and number of axles.

For tunnels, repair-shop roads, and points liable to floods, side overhead trolley contact might be arranged. Undoubtedly much cheaper coal can be converted in the power-house (in absence of gas system even) than with the restricted fire-box locomotive design, and this coal can be more cheaply transported in large *constant* quantities to the fewer points. I think the author has rather, therefore, under-estimated the power-house electromotor economies; and the Italian long-distance installation results will be very interesting (although tonnages will probably be relatively low).

With reference to cost and coal consumption, in one of last year's magazines I noted that the total costs per ton-mile, including staff and repairs, were 0·152d., 0·171d., 0·190d., on the Brooklyn Elevated, average American steam practice, and Manhattan Railway respectively (124, 138, 153 per cent.), against 0·124d. (100 per cent.) on our Liverpool Overhead Railway (electric), which latter is probably hardly now modern practice. Also it was stated that coal consumption ratio on train-mile basis was $\frac{16 \text{ electric}}{41 \text{ steam}}$; and that the greatest power-house and motor coal consumption per axle per hour was about 79 per cent. of best steam practice. I should be glad if the author could give more modern figures on those points, where it may be said that the traffic and resistance conditions make it comparable.

Mr. Taylor. Mr. A. M. TAYLOR (*communicated*): Though it may be considered by some as undesirable, in a paper of this nature, to criticise details, yet, unless the premises be correct, wrong conclusions may possibly be formed.

First, as to traction resistance. It may be presumed that, in measuring tractive resistance, the locomotive engineer will select as level a piece of the line as possible on which to carry out his tests, so as to avoid corrections due to grades, etc. His principal object is to determine the best performance he can get out of his locomotive in the way of speed, and the coal bill does not concern him to the same extent as it does the electrical engineer, whose principal object is to prove the economy of electric traction. We may then, perhaps, safely assume that losses due to the braking of trains when descending gradients do not enter into the determination of tractive resistance. This matter is,

of course, of less importance on railways than it is on tramways, on which values varying from 0·95 Board of Trade unit per car-mile to 1·7 B.T.U. have been experienced, due to this cause, with the same size of cars. Let us see whether it is a negligible quantity on main-line railways such as we are considering. The average running speed of Mr. Langdon's trains is about 34 miles per hour, and the tractive resistance for the level may be put at 7 lbs. per ton, taking his own figure. So long as the down gradient does not exceed $\frac{1}{320}$ or, say, 16 feet to the mile, it may be considered as compensating the up gradient; but if this limit be much exceeded it will be necessary to apply the brakes. In the route from London to Bedford and back again (100 miles) it is possible that there may be as much as 10 miles of track, in the aggregate, where the gradient exceeds $\frac{1}{160}$, giving a total drop of 320 feet, and 160 feet of this is irrecoverable lost energy. It is true that this would only amount to some 2·5 watt-hours wasted at the generating station for every ton-mile hauled; but if the gradients were much steeper, or longer, than I have assumed, the case would be very different. As it is, it adds nearly 10 per cent. to Mr. Langdon's figure of 26 watt hours per ton-mile for the tractive resistance alone. It would be interesting to know what are the actual conditions on the line in question. Mr. Raworth has given us an estimate of the additional power required for starts and stops (which is, of course, quite independent of that wasted on the gradients), so I do not propose to touch on this loss, which, however, seems to me to be low. Mr. Taylor.

Next, as regards the load-factor. Mr. Lackie has referred to the effect of the hourly variations of load on this question. But what I wish to call attention to is that the variations in the output from minute to minute have also no slight effect on the load-factor. The number of trains considered is, comparatively, quite small—only 14—and the fluctuations should be pretty considerable, especially when we remember that goods trains (with their frequent stoppages and starts) form a large proportion of the total weight to be hauled. Taking grades and everything into account, it will be surprising if, for an average load during 24 hours of 5,000 kilowatts, we do not require plant in the station of 8,000 kilowatts, while that of the rotary converters and step-down transformers will be nearly 1,000 kilowatts capacity (excluding spares). Bearing in mind that the efficiency of the engines and of the electrical plant falls off, after a certain point, more rapidly than the output diminishes, we can easily understand that, for an *average* output of 5,000 kilowatts, the all-day efficiencies cannot be sensibly higher than assumed by Mr. Langdon. I think one or two of the speakers seem to have hardly appreciated this point.

Lastly, I wish to say that I quite agree with Mr. Field's reported remarks as to the incorrect number of trains on the line; which do not, however, vitiate those of Mr. Langdon's figures which are based on train-mileage only.

Mr. REGINALD WOOD (*communicated*): The Institution is fortunate in having this important matter brought before it from within the railway companies. Mr. Wood.

The author is to be congratulated on having been content to

Mr. Wood.

make only a modest claim in favour of electric traction on the great railways, as no doubt the greater economy will only be achieved when the service takes advantage of the electric supply to alter its method somewhat, and to sell current *en route*.

As I take it the author desires that the discussion should show that his paper has been critically examined, I will mention what appears to me to be an omission in his statement, but as I shall point out a remedy the objection will disappear. It does not appear to me that the author claims all the economy he might in shunting.

The omission is that no mention is made of the kinetic energy of the trains. If every train stops once in a quarter of an hour we have practically one train starting every minute. This would demand an extra 1,000 kilowatts working continuously with a corresponding 20 per cent. increase in the coal bill. There are no data in the paper to enable one to state definitely whether this extra power should be 500 or 1,500 kilowatts. But there is, of course, no doubt that this is a most important matter, though it may be of more importance in suburban traffic. Anyhow, the remedy is to brake the train by returning the energy back to the contact-rails. All that is required is to substitute for the resistance in the series-parallel control a dynamo carried on the locomotive and coupled to another dynamo suitably connected. It gives the incidental advantages of smooth starting and stopping, and the attainment of any electric pressure desired at any point. That is, the electric pressure on the locomotive is under the control of the driver. He can get excess pressure if he wants it. It also gives the advantage of saving the energy usually lost over the resistance and a great part of that lost in transmission.

This is a matter rather more than of mere detail. If there is a serious objection to absorbing the kinetic energy of the train by a brake on the locomotive in front of the train, a good case can be made out for redisposing the motive power. The description of this controller is to be found in Patent Specification 23,854 of 1894. The successful inaugurator of main-line electric supply will have earned a nation's gratitude.

Mr. Merriman.

Mr. W. H. MERRIMAN (*communicated*): There is one point which has not been mentioned in the discussion on Mr. Langdon's paper, viz., the extra precautions, impossible on a steam railway, which may be taken to ensure the safety of passengers on an electric railway. A very large percentage of the accidents which from time to time occur on steam railways is due to engine-drivers mistaking the signals or running past them when at "danger." It would be a comparatively simple matter to arrange switches in conjunction with some of the principal signals, each of which would cut out a portion of the contact-rail—say four or five train lengths—beyond the signal whenever it was at "danger." Any driver then running past a signal set against him would have his attention at once called to the fact by the slackening in speed of the train owing to the current being cut off; while, at all events at night time, the guard would also be warned of the danger by the extinction of the train-lights—presuming, as is probable, that these would be supplied with current taken direct from the contact-rail. It would, of

course, be necessary to provide against the possibility of a switch being opened before a train had reached the end of that section of the contact-rail which it controlled, in the event of the signal being raised immediately after the train had passed; but this, I think, would offer but few practical difficulties. Mr Merriman.

Mr. J. BROWN (*communicated*): I observe that engineers have recently been turning their thoughts towards the contriving of some means to avoid the delay involved in stopping "local" trains at all the stations, though only a fraction of the passengers wish to enter or alight at any one station. The plan of which I send a sketch avoids this inconvenience, provides a through train for every passenger from any station to any other, and dispels all anxiety or doubt about alighting at a wrong station or being carried past the right one. As my scheme could be worked best by electric motors, and as steam locomotives would be quite inapplicable, it falls not inappropriately within the scope of the present discussion. Mr. Brown.

The sketch (Fig. B) is intended to represent an endless railway with coaches arranged ready for starting the day's work. The coaches are

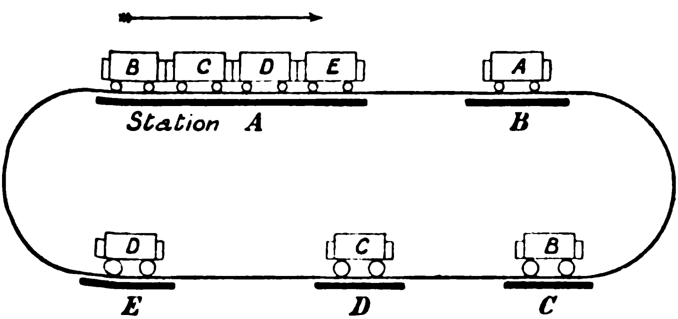

FIG. B.

of the corridor type or like American vestibule cars, so as to give a passage right through the train. Each coach has its own separate motor, and can thus run independently. A train consisting of, say, four coaches, starts from station A. As this train approaches station B, the coach A standing there is started by the driver in charge of it, and sufficient speed given to it to allow it to be picked up between stations B and C by the following train. This may seem difficult, but in reality there should be no more difficulty in picking up a coach in steady motion than there is every day in running gently up to one at rest. It is merely a question of relative motion, and with electric motors the speed would be easily and quickly controlled. If necessary, an appropriately placed signal-box would eliminate any possible risk at this point. As soon as coach A has been picked up, the driver of the train goes to its forward end and there takes control of the train, connection being made to all the other carriage motors for that purpose; or the driver of coach A takes charge of the train, and the former driver goes to the rear coach ready to slip it.

Mr. Brown.

In order to allow passengers for station B to alight, the train, as it approaches B, slips its last coach marked B, which is then brought to a standstill at station B. The same process is repeated at each station. The result is a through express for every station. The passenger simply enters a carriage standing at the platform from which he departs. As soon as it is coupled to the train he looks (at his leisure) for the carriage marked for his destination, and remains there till the carriage stops, when he can alight with ease. He may not find his carriage at once, but certainly a few stations before his destination. Two or more coaches may be slipped or picked up, of course, if one is not enough.

Although here shown as applied to endless railway, the scheme is equally applicable to a railway with termini. It would be eminently suitable for the various underground electric railways recently proposed for London. From an engineering point of view several advantages accrue which may not be at first sight apparent, viz. : A much shorter station is required than in the usual method where the whole train has to be accommodated at every platform, and considerably less power would be required since only a fraction of the train has to be stopped and started. The load would also be more constant, in fact it would scarcely vary at all.

Mr. Twinberrow.

Mr. J. D. TWINBERROW (*communicated*): Mr. Langdon has not credited the performance of the steam locomotive with possible improvement upon the existing practice of the Midland Railway.

This company appeared to favour the division of the traffic into numerous trains of low gross weight, worked by locomotives of considerable elegance but having small capacity. Recent practice in America and on the Continent exhibited a preference for fewer trains of greater weight worked by engines of great hauling and earning capacity; thus a standard American engine for mineral traffic was provided with boiler heating surface about $2\frac{1}{3}$ times greater than that of the Midland engine for a similar purpose, and recent passenger engines in France had 70 per cent. more boiler power than the express locomotives of the English company.

The small loading gauge increased the difficulty of constructing powerful engines for working on British railways, but no important modification was involved by an addition of, say, 85 per cent., which would suffice for doubling the gross weight behind the tender; he had examined the saving per net ton-mile which would result from this modification, and was of opinion that the cost of locomotive power in working the coal traffic to London would be reduced by not less than 30 per cent. This economy could be realised without great capital expenditure by devoting the current outlay for renewals to the provision of machinery of greater earning capacity, relegating the existing stock of locomotives to shunting and branch-line service, and scrapping the lighter engines as they came to require heavy repairs.

If English engineers would be guided by what had already been accomplished elsewhere, in preference to adhering rigidly to their own precedent, they would be able to effect with certainty an economy nearly twice as important as that which the author is able to deduce from a somewhat speculative basis, with the disadvantage of a heavy

capital outlay and immense inconvenience in effecting the installation. Mr. Twinberrow.

The chief sources of economy in the application of electricity to tractive work appeared to be (*a*) saving of tare weight; (*b*) increased revenue mileage per unit of labour. A saving under the first heading could only be effected in practice by applying the motors to some of the carrying axles of the vehicles; and that under the second heading was important because the steam locomotive was not an automatic machine, and required so much attention that its attendants usually earned revenue during less than one-half of the hours of duty. It was remarkable that the author's proposal did not provide for any saving under these headings.

Mr. E. KILBURN SCOTT (*communicated*): If there were no other result of Mr. Langdon's paper, it would, in the writer's opinion, have served a useful purpose in showing the difficulties of working railways by separate electric locomotives and also the objections to a system such as the Central London when applied to main-line electric railways. Even if the pressure on the third rail were raised much higher than 500 volts, there would still be objections to converting high pressure three-phase to continuous current by transformers and *rotary converters*. Mr. Scott.

Being a synchronously running piece of apparatus, the overload capacity of the rotary converter is distinctly limited. It must be made large enough to take the maximum load under the very worst conditions without falling out of step, and naturally this load is a much higher figure than is required under average conditions. Assuming sixteen trains per day, the rotary is only likely to be giving current for a few minutes every half-hour or so, the rest of the time being spent in running round uselessly. On the other hand, the static transformers required for three-phase working will take extremely large temporary overloads if there is time to cool down between the periods of overloading, consequently comparatively small static transformers may be employed, and, when running on no load, the constant iron loss is a very small percentage compared with hysteresis, eddy, commutator, and friction losses, which are constant with the rotary converter.

Comparing the three-phase Burgdorf-Thun results with those obtained on the South Side Elevated Railway (continuous current) of Chicago, worked on the Sprague system, it has been shown by Professor Carus-Wilson that whilst the continuous-current motors use 87 per cent. of the energy required by the three-phase motors, the latter get up speed in 81 per cent. of the time required by continuous current. The reduction of energy in the continuous-current motor is due to the use of series-parallel control; but there is this most important feature in favour of three-phase, that *the maximum power input required by the motors on the Burgdorf-Thun line was only about 70 per cent. of that at Chicago.* The importance of this is seen when we consider that a reduction of the maximum power input reduces materially the size of the secondary conductors and cables, the output of the transforming apparatus, the size of the main generators, and through them the engines and boilers. Above all things, therefore, any system can be pronounced "very good" which tends to reduce maximum power input.

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Mr. Scott.

If Mr. Langdon can make out so good a case on a system practically identical with the Central London, then it says much for the future for electric railway working, because there is no doubt whatever that better results can be got by adopting three-phase traction throughout. For example, the 10 per cent. loss in efficiency of rotaries would be swept away; the cost of the five substations and their equipment, given at £80,000, would be reduced to at least half; and finally, the greater proportion of the wages of the five assistant engineers, etc., at the substations, given at £5,472, or nearly 15 per cent. of the total estimated cost of generation and distribution of current, would practically disappear. Even if there were three times as many substations, the step-down transformers could be very well left to look after themselves.

The fact that certain parts of the lines are liable to be flooded, and the importance of having a standard method of picking up current puts the third rail on the sleepers, out of court altogether. It is possible to use a third rail on underground railways (although even in such situations it is questionable whether it would not be better to have smaller and less get-at-able conductors fixed overhead), but on main-line railways the difficulty of preventing people and occasionally animals getting on to the line would make the third-rail system quite too dangerous. The conductors might be put into a conduit by the side of the track, but there would be great complication at crossings and the conduit would, of course, be liable to be flooded. There is nothing for it, therefore, but to suspend the conductors on span wires immediately over the track, or else place them one above the other on poles at the side of the road. The writer thinks this latter method the best; but the point to be noticed is that as the conductors are to be overhead, it is better to have them *small in section*; in fact, it is difficult to see how anything but copper wire can be used. Now with small-section wire it is clear that to run a train the voltage must be in the nature of *thousands* rather than *hundreds* of volts.

It is, indeed, very questionable whether, at the high speeds of 50 miles an hour and upwards, the large currents required for low-voltage working could be picked up conveniently. The limit for the ordinary trolley wheel used on tramcars seems to be about 25 miles an hour, but the Siemens bow and the collecting shoe will pick up current at higher speeds; everything, however, appears to depend on the amount of current. Messrs. Siemens and Halske have recently made experiments with special bow trolleys, moving horizontally, picking up current from three conductors fixed at the side of the road. The arrangement works very well indeed, and it is found that the collection is best at the higher pressure of 10,000 volts. Having three conductors at the side of track makes an exceedingly neat arrangement, as there are no span wires and the bow contact allows plenty of variation in height for sag. Should one trolley miss the wire, the motor will still continue to run on the other phases.

With steam traction it is necessary, in order to reduce expenses, to make up trains of considerable length, so long, in fact, that it is not an unfrequent occurrence to have to pull up a train twice at a wayside platform. Now with electric traction there is no advantage in having

long trains; in fact, it is rather the reverse, as current is always on tap, as it were. Short trains run at frequent intervals, give a more even load, and as the staffs at the various stations are more regularly employed, there is a more punctual service and an improvement of conditions all round by enabling traffic and luggage to be handled with greater facility. As Prof. Carus-Wilson rightly points out, the main-line railways pay fairly well as they are; it is the short branch lines with half a dozen or so trains a day which form the non-paying portions of the railway systems. Several such lines, worked electrically from a common central station, could no doubt be made to give nearly as good results as an electric tramway, and by feeding the trunk lines more regularly would lead to an improvement of the system. Mr. Scott.

For the benefit of those speakers who seemed to think that a number of small stations are preferable to one large one, it may be mentioned that before deciding on the one station of 100,000 H.P. on the East River frontage, New York, the Engineering Board of the Manhattan Elevated Railway thoroughly considered nine different schemes, most of them being *for more than one station*. The total length of third rail on this line is 75 miles, and three-phase current is generated in the central station at 11,000 volts.

Mr. LANGDON then replied briefly, but the full text of his reply, with remarks added subsequently, is printed at the conclusion of the discussion at Local Sections meetings (see p. 218). Mr. Langdon.

The PRESIDENT: I think, gentlemen, you will have no hesitation in according to Mr. Langdon your warmest thanks for his paper The President

The vote was carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Associate Member:
Alfred Henry Bland.

Associate:
Ernest Philip Alphonso Law.

Student:
Samuel Blackley.

NEWCASTLE LOCAL SECTION.

The Newcastle Local Section of the Institution of Electrical Engineers met in the Chemical Lecture Room, Durham College of Science, Newcastle on Tyne, on Monday, the 10th of December, Mr. A. W. Heaviside (Chairman) in the chair.

DISCUSSION ON MR. LANGDON'S PAPER ON "THE SUPERSESSION OF THE STEAM BY THE ELECTRIC LOCOMOTIVE." (*Read in London, November 29th,* 1900.)

Mr. Dobbie.

Mr. R. S. DOBBIE: In the paper before us, the question of the money represented by the carriage of the necessary coal and water for steam locomotives over a large number of train-miles was not brought forward as strongly as it might be. It represented the transportation of a heavy dead-weight from which no income was derived. The paper confined itself, when treating of electric traction, to the use of electric locomotives. The modern tendency is to use a large number of motors; in fact, one on every axle of the train, and the cars are controlled either individually or collectively by controlling devices operating from any one point. These principles have, I believe, been put into operation in the city of Brooklyn, U.S.A., and are called by the inventor, Mr. Frank Sprague, the well-known pioneer in street railway work, "The Multiple Unit System."

Mr. Turnbull.

Mr. C. TURNBULL: With regard to the statement that the coal would be saved which is at present used by locomotives standing in sidings, etc., I think that this would be considerably counterbalanced by the coal used in keeping steam on the boilers at the supply-station sufficient to meet the maximum demand, which would only come on at intervals. This point would be best dealt with by finding out what actually are the losses on locomotives from this cause. With electric trains it may be possible to develop a method of setting down and taking up passengers from moving trains. This could be done by slipping a motor-carriage off from the main train with passengers who wanted to be set down, while another motor-carriage could be run up to the main train with the passengers who wished to join it. This would mean that the main train would have to slow down a little to allow the motor-carriage to catch up to it. Possibly this disadvantage could be got over by sending the carriage on first and allowing the main train to catch up to it. I think the experiment might be tried in some form on our suburban lines. It would act somewhat in the manner of the moving platform of the Paris Exhibition.

Mr. Ralph.

Mr. G. RALPH: I take it that the whole object of the proposed change to electricity as the motive power for trains is to effect economy in the working expenses. Given that is so, I should like to draw attention to another point where economy might possibly be

effected which applies equally to electric and to steam traction, and that is the saving of power by the use of roller-bearings. It is well known that these bearings reduce the bearing-friction in a very marked degree, and it is a matter of surprise to me that no experiments have been made in connection with these by the railway companies. I made some tests a few years ago on an ordinary railway-coach, first with the ordinary bearings, and then with the same coach fitted with roller-bearings. The ordinary bearings required about 45 per cent. more power to run the coach at a given speed than when the roller-bearings were fitted. (This was at a low speed, about 10 miles per hour.) It is possible that they would not stand the rough usage of railway work, and I am not prepared to state how long they would wear, though it is stated that on an electric railway at Rhode Island, U.S.A., rolling stock fitted with them ran for 21,000 miles and no appreciable wear could be detected. It seems well worth while giving them a trial. Mr. Ralph.

Mr. Dobbie: As to the matter of roller-bearings on street cars, they certainly save a large amount of current at the moment of starting, but whether they save much energy during the running of the car I cannot speak. I have lately applied ball-bearings to motors, etc., and by a careful series of tests I found that in a particular motor of 3 H.P. with well lubricated bearings, the substitution of ball-bearings in the same motor showed an apparent gain in efficiency of only 1 per cent. I may state that ball-bearings are used by me with quite another intention than to gain efficiency. Mr. Dobbie.

Mr. G. Ralph: I quite agree with Mr. Dobbie that there is a very great reduction in the starting pull when roller-bearings are used, but in addition to this the tests which I referred to clearly proved that there was also a large saving in the actual *running* at that speed, since the watts put into the motor were 20 per cent. less, and at the same time the speed increased 25 per cent. when the roller-bearings were substituted for the ordinary brasses. When reduced to the same speed, these figures show that with ordinary bearings 45 per cent. more power is required. Mr. Ralph.

Mr. Dobbie: The roller-bearings I have seen, and with which the starting current was undoubtedly reduced, probably as Mr. Ralph states by 30 or 40 per cent., were the Hyatt patent, the rollers of which are made of slightly flexible steel spirals, which accommodate themselves and automatically distribute the load on half the rollers more or less. Mr. Dobbie.

Mr. O. L. Falconar: Mr. Dobbie has mentioned something about saving dead-weight. I should like to know what would be the weight of a large electric locomotive, equal in power to some of the large N.E.R. passenger locomotives. I think it would come to a considerable amount. It occurred to me that an electric locomotive would require extra weight to provide the necessary amount of adhesion for the wheels in starting, so the saving might not be so great after all. Perhaps Mr. Holmes would give more information on the matter. The multiple-unit system is, I think, the most reasonable method for passenger trains, but I do not know how they would manage with goods trains. Mr. Falconar.

Mr. J. H. Holmes: With regard to the multiple unit system, I am Mr. Holmes.

Mr. Holmes. not familiar with the details of the system, as I have not had an opportunity of seeing it in operation, but I think Mr. Dobbie has had an opportunity of seeing it and will have a better idea of the matter. The controllers at the end of each car are all worked electrically by small electric motors, arranged to work in unison with each other, so that the driver handling one controller at one end of the train, will work all the motors in the train. Of course, the system is not used with the electric locomotive, but it practically gets over the difficulty of having a heavy electric locomotive at the end of the train.

The question of roller-bearings is a very interesting one, and as we have had such very different figures submitted to us this evening, it seems to point to a difference in quality. It seems to me that a roller-bearing to be effective, should be as hard as possible so that it can keep its shape, and roll evenly on the hardened surface, and if the surface is correctly made it ought to work perfectly.

With regard to the question of changing over, I can see a difficulty in changing over to the electric locomotive from the steam locomotive. If the change would involve the same amount of confusion on our railways as we are now experiencing in Newcastle on our tramways by changing them from horse-power to electric power, I do not think we should like to make the change just at present.

Mr. Dobbie. Mr. DOBBIE: I think if it is looked into, that the principle of a spring roller is the correct one. The amount of deformation is only a few thousandths of an inch or so, and if this slight spring, which is not beyond the elastic limit, has the effect of distributing the load on a number of the rollers, it is evidently better than that the whole stress should be expended on one, or on a part of one, glass-hard unyielding piece of steel. I have seen the Hyatt roller-bearings in a train of rolls for sheet metal, where, with hardly any lubrication, they operated successfully, the bush in which they ran being of cast-iron lined with a spiral made of steel strip in the same way as the rollers themselves.

Mr. Wood. Mr. L. WOOD: If the line voltage were to be 3,000, as the engineers of a proposed Italian railway hoped to use, and feeder voltage were raised to 20,000 or even more, there would be a great saving in the cost of conductors which would be one of the heaviest items in the cost of conversion. Presumably the feeder cables would be laid in iron pipes along the permanent way, and might perhaps be advantageously made concentric with the outer conductor, bare and earthed. The current on the motors would be three-phase, which appeared to have, under some circumstances, advantages over direct current.

Mr. Heaviside. Mr. A. W. HEAVISIDE: Now that we know that high speeds up to 100 miles an hour are contemplated in electric traction, does it not become important that the form of the surfaces presented to the air in the direction of motion should be such as to offer the least resistance, as in the torpedo boat or the body of a bird?

Mr. Dobbie. Mr. DOBBIE: With reference to the high speeds mentioned, many years ago Mr. O. T. Crosby ran an electric locomotive at the rate of 120 miles an hour, and the trouble experienced in maintaining the insulation led me to patent the placing of the armatures on springs

around the axle so that vibrations were not communicated. Engines embodying this principle have been made up to 45 tons in weight to run with a heavy train about 30 miles per hour. As for such speeds as 120 miles per hour, although there is nothing impossible in them, I should be very satisfied if we could run up to London at 50 or 60 miles per hour behind an electric locomotive. Mr. Dobbie.

The matter of shaping the locomotive and, indeed, the whole train, has already had attention. Mr. Heilman has studied the shape of the front of the locomotive, and the Philadelphia and Reading Railroad has experimented with a train of cars made to present as smooth a surface as possible to prevent what naval architects call "skin-friction," and reach speeds of over 80 miles an hour.

Mr. A. W. Heaviside: With regard to Mr. Turnbull's objection to large central stations of the Willesden type which he instances, it must be remembered that it is a pioneer station of its class, if one may except Ferranti's Deptford power-house (somehow Ferranti always points the way). The aim of such stations is to get a mean steady load by distributing over an area of many wants arising at different times all through the day, and Mr. Langdon's proposal is on these lines. Their success will depend on the productions gains of such a load not being swallowed up by the distribution-losses. Already much information exists as to the cost of such a load, as, for instance, in the running of alternating-current stations. Continuously energising transformers over a wide area throughout the whole year is an example, and, as regards cost, one farthing per horse-power, where coal is cheap, is not wide of the mark. Mr. Heaviside.

After the advantage of having read the criticisms of the technical press, I think that Mr. Langdon understands the principles underlying the whole thing, and though much will have to be done of an experimental character before main line railways are run electrically, the beginning has come now.

As it is growing late, I think we should close the discussion for this evening, but not without putting on record how much we thank Mr. Langdon for his paper.

The vote was carried by acclamation.

GLASGOW LOCAL SECTION.

The Glasgow Local Section of the Institution of Electrical Engineers met in the Institute Buildings, 207, Bath Street, Glasgow, on Wednesday, the 12th of December, at 8 p.m., Professor M. Maclean (Vice-Chairman) in the chair.

DISCUSSION ON MR. LANGDON'S PAPER ON "THE SUPERSESSION OF THE STEAM BY THE ELECTRIC LOCOMOTIVE." (*Read in London, November 29th*, 1900.)

The Chairman.

The CHAIRMAN, after giving a short summary of the paper, read the following communication which the Hon. Secretary of the Section (Mr. E. George Tidd) had received from Mr. Langdon :—

Mr. Langdon.

Mr. LANGDON (*communicated*): Your Section is to do me the honour of discussing my paper on the "Supersession of the Steam by the Electric Locomotive" on the evening of the 12th.

I hope it may not be thought that in submitting for the consideration of your Chairman the following observations I am attempting in any way to direct or influence the discussion, but questions having been raised on the occasion of last Thursday's discussion, at the Electrical Engineers in London, of the accuracy of the formula employed by me for obtaining the pounds tractive effort per ton, on which of course my calculations are very largely based, I am particularly anxious that this important question should, if opportunity arises, be dealt with. It may be that you may be favoured with the presence of locomotive or mechanical engineers who may be prepared, if the formula which I have used is in their opinion inadequate, to furnish a formula which they may regard as reliable. I may perhaps add that I have every confidence in the source from which I received the formula which I have used. I know it to be the result of a number of practical experiments, but I have not yet ascertained that it is applicable to goods trains. The various formulæ given do not attempt to make a distinction between goods and passenger trains. If reference is made to the diagram furnished in Fowler's "Mechanical Engineer" Pocket Book for 1900, it will be seen that there are three curves which practically coincide whilst that of Clark's deviates from these three to a very great extent.

"Molesworth" expresses Clark's as follows :—

$$6 + {\cdot}009\ V^2.$$

If this is carried out in respect of the No. 1 class of train shown in my Table IV., it will be found to result in a per train horse-power of 1,045 as against 477 by the formula which I have used; and if it is applied to No. 4 class of train, the demand will be 386 horse-power as against 183.

The difference is, as you will see, very great—indeed so great as to raise the question whether a steam locomotive, travelling at the speed of fifty miles an hour, could give that horse-power output.

Another point commented upon was the scheme of plant. Whether it was more desirable to employ a central generating station, supplying certain sub-stations, or for the sub-sections to be provided for by, what I may perhaps call, local generating stations. I am clearly of opinion that those who argue in favour of local generating stations have not thoroughly appreciated the many advantages that attach to the central and sub-station system. If each section is to be worked by local generating services, then the machinery established and in operation must be sufficient to meet any demand that may arise on that section, which would mean an increase in cost for plant, coal and labour. It would be impossible to guarantee a fixed demand. The varying difficulties which arise in working trains at the present time will not be inseparable from trains worked electrically. Practically the same conditions will attend them. The load in the several sections will be continually varying. With a central generating system the load, as it shifts from one section to another, will not vary to any great extent the load at the central station — that will remain practically constant, depending upon the *sum total* of the load comprised within the demand of the several sections served by the central station. Mr. Langdon.

Another argument in favour of the central station and sub-section system is that it will be capable of meeting, to a large extent, without stress, the varying demand consequent upon the starting of trains. At the moment when inertia is being overcome in one place, there will no doubt be a relaxation of the demand for power at another point—*i.e.*, as an instance in point, a train may be running into a station simply under the influence of momentum without any help whatever from current, whilst at another station a train may be starting and will require, for a moment of time, a large accession of current. Of course this would apply to some extent in a local section generating its own current, but it will apply very much more largely with the central station scheme—that is, as it will take a larger area, so the opportunity for equalisation will be greater.

If after reading this you should think that the matter I have taken the liberty to submit to you is of sufficient importance to read to the members at your meeting, I should feel obliged if you will do so. My great desire, of course, is to get at reliable data. In adopting the formula which forms the basis of my calculations I placed, as I still do, every confidence in it; but if it can be proved to be wrong to such an extent as materially to modify my deductions, it would be only honest that such should be done. I need hardly, however, add, that the matter is one of so great importance, that there should be no doubt as to the absolute accuracy and source of any formula that may be advanced in place of that which I have used.

Since inditing the above, I have received from the author of the formula used by me a communication thereon, copy of which I append. The data was, as you will see, collected from actual experiment in 1891, since which date the tendency due to improved lubrication, etc., should be, if anything, to reduce the tractive effort result.

Mr. Langdon.

"MIDLAND RAILWAY, LOCOMOTIVE DEPARTMENT,
"DERBY, *Dec.* 10*th*, 1900.

"W. LANGDON, ESQ., Derby.

"DEAR SIR,—I am sorry that I was unable to be present to hear your paper read, and offer some facts in support of the train resistance figures you submitted, for I quite agree with your conclusions on this matter.

"The formula you have adopted agrees with the results I obtained in 1891 with trains running on the Midland Railway between London and Nottingham. In all, about four hundred sets of figures were taken, and in calculating the train resistance from them, proper allowance was made for gradient acceleration, energy of revolving wheels, etc.

"The results agree closely with others obtained by Barbier, Du Bosquet, and other careful investigators. The train resistances at high speeds given by Clark and some others are quite unreasonable. The coal and water consumption of a locomotive is well known, and if such high train resistances were met with we should have to take it that locomotives sometimes run as economically, or even more so, than the best stationary compound condensing steam engines.

"Barbier found that the locomotive resistance was greater than that of the train. A comparison of the resistances I found for long trains as compared with short trains on the Midland do not support this view. He also found that four-wheeled coaches offered greater resistance than bogie stock. The figures you have quoted are about midway between those given by Barbier for the two kinds of stock.

"It must be remembered that, on the Midland, every care has been taken to use the best possible form of axle-bearing for coaches and waggons, and to lubricate the bearings, also, as perfectly as possible.

"The locomotive has also been designed, as will be seen upon reference to Mr. Johnson's presidential address, with a view to reduce frictional resistance in every way.

"It should be borne in mind that even if some steam locomotives offer greater resistance to motion per ton than do the trains they draw, such would not be the case with the electric locomotive, owing to its shape, small size as compared with its weight, evenly distributed load, and absence of all friction except that of the journals.

"The figures found for passenger trains will, I think, also apply to goods and mineral trains.

"Should you desire to do so, you may, with pleasure, make use of this letter.

"Yours sincerely,
"(*Signed*) R. M. DEELEY."

Mr. Mavor.

Mr. H. A. MAVOR said that Mr. Langdon's paper appeared to him to be a most useful one for the initiation of the discussion to which it had given rise. There were about forty-four electric railways authorised by Parliament in this country. Four of these had come into operation. It seemed on the face of it that the figures in the paper were of less importance than the subject itself. Mr. Langdon had pointed out that the prime factor was that of efficiency in the generating plant and the

electric transforming plant, and in transmission. He (the speaker) did not quite agree with Mr. Langdon. The figures in Table VII. as to the generating charges would indicate what he meant. The charges there formed a comparatively small proportion of the total estimated by Mr. Langdon. He (Mr. Mavor) thought they ought to bulk more largely. According to the paper the generating charges were somewhat less than one-quarter of the total cost for power and haulage. The whole question before them, however, ought to be looked at broadly. What was the probability with regard to the relative efficiencies of steam locomotives running on the line, each with its own boiler, and the large engine combining the power of fifty locomotives? It would be pretty evident that the large engine was probably most economical, not only in what might be called mechanical efficiency, but in general working. Seeing, however, that from the data before them up to the present it was not possible to consider the efficiency except from the standpoint of what was to be obtained from test results, the question resolved itself into one of experience. Now the experience of fuel consumption for an electric train, as compared with steam locomotives, was not available to any large extent. Some of the other items were comparable, and it would not seem unfair to draw comparisons from the experience on street railways in this country. Of the facts which had been given to them with regard to the working of street railways, the figure in connection with the renewal of plant comes out as low as 10 per cent. of the total in some cases, and as high as 20 per cent. in other cases, but in no case does it approach the 30 per cent. spoken of in Table VII. in the paper. They had much to learn, however, from experience upon this and other items, but what little experience they had went to show that the saving in electric transmission would be found in the replacing and renewal of plant even more than in the item of coal, though it might reasonably be expected that in the latter there would be a great saving. Mr. Mavor.

With regard to the position of the station, it would appear that Mr. Langdon's contention in favour of the large engine was likely to be modified by cousideration of the question in detail. Mr. Langdon had pointed out in his letter that the large engine could readily deal with a large load at various places, but did he remember that the sub-stations would have to be proportionately increased in size? With reference to the $2\frac{1}{2}$ per cent. leakage on the line allowed by Mr. Langdon, the speaker thought that such a leakage would soon dispose of the line altogether.

Concluding, he wished to say that Mr. Langdon's general conclusions seemed to him more valuable than his particular data.

Mr. Dyson agreed with the previous speaker that while Mr. Langdon's paper was a valuable one, its worth lay more in the general considerations which it contained than in the detailed figures in it. Before anything like a detailed estimate of the probable cost of electric traction could be arrived at, far more fixed data had to be got hold of than those in connection with the formula which had already been criticised. It was not necessary at present to discuss the different elements that go to make up train resistance, but the speaker thought Mr. Dyson.

Mr. Dyson. that all engineers were agreed that the train resistance worked out on the average to a higher figure than that given by Mr. Langdon's formula. That was a point, however, regarding which locomotive engineers would be in a far better position to give facts than would electrical engineers. Speaking of the paper more generally, the question of the efficiency of the various parts as given on page 134 of this paper, this seemed to him to be not very definitely settled. The aggregate efficiency of the system, as given by Mr. Langdon, was 58 per cent., but of the items which on that page go to make up general efficiency there were two or three that seemed to him (Mr. Dyson) to be very doubtful. With regard to static transformers, their efficiency was given as 93 per cent. He thought 98 per cent. would be nearer truth. The efficiency of rotary converters was given as 90 per cent. He thought this should be 95 per cent. The loss in rails was set down as 10 per cent. It seemed to him that this could be given as less than 10 per cent. On the question of motors, Mr. Langdon had assumed that the dearest motor may have an efficiency of 85 per cent., but the speaker thought it was not the pronounced success that the old induction motor was, and 78 per cent. would be nearer the mark than the 85 per cent. allowed by Mr. Langdon. On the whole question of efficiency, as Mr. Mavor had said, one of the things to be fixed was what should be the relative efficiency of large plant, grouped in one central station, over a large number of isolated locomotives. It seemed to him that the economy of the large generating sets, when the total efficiency of the whole system showed a drop of 40 per cent., had to be accounted for by some other means than that of the economy of steam consumption of the different classes of power. Locomotive engines, running non-condensing, would not have anything like the efficiency of large stationary plant, but he questioned whether the difference would amount to 40 per cent., and he would rather be disposed to put it down at 20 per cent.

The speaker said in conclusion that he thought the first thing to be done in advancing the subject at all would be to get together some railway engineers of experience, and some men of experience in electric traction, and let them form a committee. If, as the result of the paper, this were done, even though it did not immediately lead to the adoption of any system of electric traction over steam locomotives, it would at least advance the cause of the profession, and would greatly redound to the credit of the Glasgow Section of this Institution.

Mr. Morton. Mr. David Home Morton: You, sir, and one or two members of the Council have honoured me by inviting me to take part in the discussion of a very large subject. My contribution to-night will not, I fear, be of great service, though a few years ago I was charged with all manner of facts and figures relating to this great question of traction. Then I had the greatest difficulty in arriving at anything like reliable conclusions from the facts which were available, and I do not know that after studying Mr. Langdon's paper my position is very different, although every year facts are accumulating, which will enable us more and more to dispense with estimated figures.

If one is to be esteemed an advanced engineer to-day, one must

Mr. Morton.

believe in the electrical transmission of power and in the internal combustion engine. I believe in the electrical transmission of power and in the internal combustion engine, but I am not lost in adoration, nor do I believe that there is but one method of generating and but one method of transmitting and distributing power. Rather I believe that, when equal skill and zeal are exercised in each case, the difference between one system and another is never so great as the retained advocates of each would have us believe. Each system has its physical limitations; those of electrical transmission are the widest, therefore electrical transmission is likely to be the most universally employed.

The retained advocates of electricity are characterised by an enthusiasm and a cheerful optimism which enable them to meet their disappointments with smiling faces. Enthusiasm is necessary; without it no great work has been carried through. Probably also optimism is necessary, because if promoters and directors knew beforehand how much the cost of their enterprise would exceed, and how much the profits would fall below the estimates, they would not often have the courage to begin, and the public would not grant them the wherewithal. The contract prices usually exceed the Parliamentary estimates, the adjusted cost is much in excess of the contract, and, even if the working expenses are all right the extra load of capital tends to absorb the anticipated gains. The investor has to be content with very small returns. He benefits chiefly as a member of the commonwealth; in the present case he has an improved means of travelling, but although he is a part proprietor of the road he has to pay his fare. Although these are facts, we engineers need not fear that enterprise will cease. Gambling is inherent to human nature.

In making these remarks, I believe you will absolve me from any ill-natured desire merely to find fault with Mr. Langdon's figures and his deductions therefrom. I think Mr. Langdon is to be congratulated for putting these figures so fully and so fairly before us, showing us his methods, telling us where he has made omissions which may affect results, and where he has deemed himself entitled to claim reductions.

When there is a large volume of parallel experience, close estimating is quite legitimate; but in new departures of magnitude, all experience teaches us that, after making our calculations, we ought to make a handsome addition to estimated capital and to add a prudent fraction to the estimated working costs.

When the estimates for the conversion of the Metropolitan Railway to electric traction are made public, we shall see how widely different are the ideas of experienced combinations of men in regard to cost or to profit. Unfortunately, few of us will know whether it is profit or cost which accounts most for those differences, and we shall have to wait a considerable time for returns of running expenses.

Very properly Mr. Langdon points out that electric traction and electric locomotives are accomplished facts, and generally we know that their use has been attended with a very fairly satisfactory measure of commercial success. Mr. Langdon, while seeking to widen the field of operation, foresees that the process of conversion must be gradual. Almost all our great trunk lines are in possession of a considerable

Mr. Morton. mileage of urban and suburban roads, and much of this mileage is in tunnels. Competition with independent railways electrically worked, with municipal electric tramways, and the pressure of public opinion in favour of improved travelling conditions, will compel the introduction of electric traction on at least some of these urban and suburban lines. And the commercial results which attend the working of these lines will determine whether or how soon electrical haulage will be tried on trunk lines.

For good reasons perhaps, Mr. Langdon has not deemed it desirable to build his estimated figures on, or to supplement these by some examination of those which are actually realised and available.

The works accomplished in this country are the City and South London Railway, the Liverpool Overhead Railway, the Waterloo and City Railway, and the Central London Railway. Of the latter two it is rather too soon to speak, although the last named will tell us most in regard to that which we seek to know. Of the two former, the City and South London Railway has been in operation since 1891 and the Liverpool Overhead Railway since 1893. I take the figures as from the accounts made up for railways in accordance with the requirements of the Board of Trade, and therefore comparable with those quoted and estimated by Mr. Langdon for the 50-mile section of Midland line, covering the same items as far as comparison can be made. Neglecting the first three and a half years, when the expenses of the pioneer line were naturally rather excessive, we find that the cost for locomotive power has averaged 6d., and that it seems now to be stationary at 5·85d. per train mile. This line, as you are aware, is worked by locomotives.

The figures of the Liverpool line are more favourable, and the cars are worked by motors on their bogie axles. The cost of locomotive power since the opening averages 3¾d., or slightly less, and has been fairly uniform since the beginning, standing now at a trifle over 4d., owing probably to the higher price of coal. The Liverpool figures may be taken as an argument in favour of motor-equipped cars instead of locomotives, but it will be wise not to lay too much stress on this. The South London line was the pioneer, the Liverpool line was built in view of all the experience gained in the other; a tunnel line has difficulties and extra expenses of its own, and the Liverpool line is what may be termed a very easy road.

The Central London has chosen locomotives, and each case must be separately considered. For short trains running on short lines with fixed terminal points motor-cars are admirably adapted, but the difficulties multiply with the length of trains and tracks, and with departures from the elementary simplicity of running cars back and forth between fixed points.

On trunk lines the tendency seems to be to seek gains and economies by pulling longer and heavier trains rather than by shortening the trains and increasing their number; while on urban lines the frequency of trains is strictly limited by the block system of working and signalling, therefore long trains must be hauled to accommodate *not* the average traffic, but the maximum which occurs only during a few hours

of the day. Hence doubtless the long trains of six or seven cars on the Central London line, and I doubt if at the present time any trunk-line manager or superintendent would look at motor-cars, even though they would be easier on the permanent way than locomotives. Mr. Morton.

Reverting to the figures taken from existing lines, I shall be told that they are not applicable; the distance between stations being short, a great part of the work consists in accelerating the trains. This is true in a measure, but observe the other conditions which justify us in expecting a figure much lower for these lines if Mr. Langdon's 7d. per train-mile is right for trunk lines. The short sections represented by these small lines are well filled with trains, certainly more than one to each half-mile of double track as against three in a ten-mile section, and the gross weight of the trains in each case is only forty tons, including locomotive or motors, full complement of passengers seated and a proportion of standing cargo; very different from the trunk-line loads, which range from two and a half to ten times greater—100 to 450 or 500 tons per train. Then, again, take the classification of trains on the trunk section. Only 20 per cent. to 22 per cent. are express, and 40 per cent. are ordinary goods and mineral trains. The amount of stopping, starting, shunting, and manœuvring which is performed by ordinary mixed goods and distributing mineral trains can at any time be studied by any one who is sufficiently interested. Apart from the not insuperable difficulties attending the putting down of installations for shunting, this is a serious item not to be lightly set aside.

An ordinary branch-line train, with a 45-ton steam locomotive, five old-fashioned coaches of ten tons each empty, seated for 200 passengers, and weighing, say, 100 to 105 tons gross, can be hauled for 6d. per train-mile, including all ordinary repairs and renewals, and we are yet without evidence that 100 tons can be hauled electrically for less. The Central London will give us the first information. The trains are heavy and comparable with urban steam lines, while the C.L.R. locomotive is 43½ tons weight, nearly that of the tank locomotive, which is forty-five to fifty tons in full order. The tank locomotive, by the way, is on the Metropolitan Railway only 28 inches longer than the C.L.R. locomotive over the buffers.

The proper consideration of the subject is beset with difficulties, and we must wait for progressive experience, and this will give us time to study the difficulties. Of these Mr. Langdon has called attention to the most important. There is the great question of shunting at complicated junctions and sidings, and there is the struggle against the elements, snowstorms and floods.

The efficiency of the steam locomotive is an interesting though not a necessary factor in this discussion. The question seems to be essentially commercial.

Placed on the trestles, I have no hesitation in saying that the mechanical efficiency of the steam locomotive $\frac{\text{B.H.P.}}{\text{I.H.P.}}$ is 90 per cent; for a four-coupled engine a trifle less perhaps. On the track the conditions are very different from those in the testing room. Accurate dynamometer observations and cylinder indications are difficult to

Mr. Morton. obtain, and the most accomplished experimenters, after taking much pains, tell us that results can only be regarded as approximations. All conditions which affect results are in a state of continual change—the train is at one time tending to lag behind, then tending to overtake the engine; then the retarding effect of curvature comes into operation, and wind pressure may actually double the required draw-bar pull, under conditions when the pull would otherwise be moderate. There are also difficulties with the indicator owing to the presence of water in the steam. The most recent and most useful experiments are probably those made by Mr. W. M. Smith for Mr. Wilson Wordsell with five express locomotives on the North-Eastern Railway. The draw-bar efficiency ranged from under 60 per cent. to over 80 per cent., averaging about 65 per cent. of the I.H.P. It is fair to say that lower results have been quoted as the outcome of experiments on the Continent and in America. Sixty-five per cent. is a very fair efficiency, and it may be necessary to remind some young members of the audience that the motor axle efficiency of the electric locomotive is a very different figure from that of the draw-bar. The causes tending to lower draw-bar efficiency are present in both classes of motor, though probably in a lesser degree in the electric motor, and in the present case the loss caused by maintaining the engine and tender in motion is but a trifle more than the rate per ton required to pull the train. It could not well be expected to be less, seeing that it is the leading vehicle. The locomotive boiler is admittedly an efficient evaporator, comparing well with good stationary practice, and in the present case the water used averaged 26·5 lbs. per I.H.P., the engine in this case being non-compound. With a compound engine, taking the results of Mr. Webb's experiments on the two classes of engines, the steam consumption should be about 20 per cent. less, and if steam consumption were the first consideration a simple engine could be worked at 23 lbs. per I.H.P. These figures indicate that the steam locomotive is a fairly efficient machine, and when we remember that there is only one conversion of the energy between the boiler and the work to be done, as against four or more conversions or transmissions between the boiler and the work in an electrical system, the supersession of the steam locomotive does not look more promising in regard to net efficiency than it does in regard to net cost. And the steam department of a large central station has important losses peculiar to itself; the gross steam consumption for power delivered bears too often a very disappointing relationship to the net test consumption of the generating units.

I wish to draw your attention to the comparative expenses of the Liverpool Overhead Railway, the City and South London Railway, and a well-known local line, the Glasgow District Subway, which is worked by direct cable haulage. Do not fear that I am about to advocate this system for trunk lines. I have referred to physical limitations, and those of the cable system are perhaps the narrowest of all, though within its limits and under proper conditions the results obtained are certainly remarkable. I only bring in these figures because of the lesson they seem to teach us in regard to electrical traction.

The accounts are made up for all three lines in the same manner for B.O.T. returns, and the cost of locomotive power per train-mile stands thus :— Mr. Morton.

G.D.S.	L.O.R.	C. & S.L.R.
2·89d.	3·68d.	6·04d.
Total working expenses per train-mile—		
7·13d.	13·94d.	15·95d.
Receipts per passenger—		
1·26d.	1·96d.	1·92d.
Ratio of expenses to receipts—		
49·1 per cent.	60·8 per cent.	59·7 per cent.

If the earnings on the Glasgow District Subway per passenger were equal to the mean of the earnings of the Liverpool Overhead Railway and the City and South London lines then the ratio of expenses to receipts would be :—

G.D.S.	L.O.R.	C. & S.L.R.
32 per cent.	60·8 per cent.	59·7 per cent.

If it is objected that the trains on the Subway are lighter than those of the other lines, and that they have a smaller seating capacity, I may say that increasing the capacity of the cars would have only a most trifling effect on the results owing to the system of traction, that the car mileage is much higher than for the other lines, and that taking last year the passengers carried were :—

G.D.S.	L.O.R.	C. & S.L.R.
13,665,560	9,690,236	6,983,040

In the Subway power-station there are only two simple though high-class non-condensing engines, one in reserve, while on the other lines the engines are compound and condensing. To meet a moderate increase of traffic and a small addition to the lengths of the lines, the power plants of both electrical lines have been already largely increased and reorganised, while the existing plant on the Subway is capable of dealing with all the trains which could be put on the line under any reasonable system of working.

There are, of course, reasons for the low costs attending this example of cable haulage, and the chief reason is found in the compensation or return of energy to the driving cables by the cars which are descending grades, and by reason of the fact that cables on different tracks are virtually coupled together in the power-house ; cars descending on one line actually assist those on the other tracks. The energy stored up in the engine fly-wheels, and in the cables themselves is also called upon by the cars, so that the average and maximum powers are made less than would be possible in the absence of a compensating system.

Now there is a considerable analogy between a cable haulage and an electrical traction system, the third rail or conductor representing the traction cable, and when we have succeeded in restoring to the conductor a great part of that energy which is now dissipated by descending trains in pulverising wheels, tracks, and brake blocks, we shall have

Mr. Morton. taken an important step towards reducing the cost of electric traction. I am aware that the attention of electrical engineers has already been directed to this question. The figures which I have quoted give some indication of the advantage which may be obtained, and the works already done by electrical engineers is indication enough of their ability to solve this problem.

Prof. Barr. Professor BARR expressed his dissent from Mr. Morton's opinion that electrical engineers were characteristically too sanguine and too optimistic, though he admitted that there had been a time when some of them were so. He instanced the case of an electrical engineer whom he had met at the Glasgow Gas Exhibition of 1881, and who in the course of conversation had assured him that incandescent electric light would be in use in every house within a year from that time.

Continuing, the speaker said that he thought that the question before them of the supersession of steam by electricity for locomotives, was a problem in which the arguments for Electricity were more favourable than in many other cases to which it had already been successfully introduced. There could be no doubt that in a great measure the economy obtainable in stations for lighting and tramways was limited by the nature of the load-factor. There was no case equal to a large main line for constancy of load-factor. He (the speaker) did not think that Mr. Langdon had in that matter done his case at all justice in his paper. He thought that it would be found that the load-factor would come out very much more constant than is stated in the table in the paper, as would be seen if the number of trains on the whole line, instead of the number passing a given point during a given interval of time, were considered.

It was a pity that they had not more results before them, but he thought that as far as could be judged from appearances, electric traction would not come in through the calculation of probable economy alone nor even mainly, but in virtue of the obvious advantages the system possessed in special cases over steam haulage. The underground railways, he said, would some day be compelled, by public opinion, to use electric traction, and he thought also that the time was not far distant when they should have a great deal more objection to the running of locomotives in the vicinity of cities than was yet manifest. A great deal of the smoke nuisance in suburban districts had been proved in many instances to be caused by locomotives.

Concluding, he said that he had no doubt that under the compulsion of a growing public opinion on the subject, the time was coming when they should see a very large development of electric traction even on main lines, and he personally would be very glad to see electricity substituted for the present objectionable locomotive in the cases to which he had referred.

Mr. Lackie. Mr. W. W. LACKIE: None can doubt Mr. Langdon's remark that the consideration of this subject can only be attended with good. It is a large problem to tackle, but his conclusions and results are most satisfactory. I would, however, like to draw attention to some of the figures and conclusions come to by him. It is shown that the maximum number of trains per hour varies from 19 to 7. If this is the case, it

means that he cannot have, as he states, an absolutely constant load and station output for every hour of the day. His figures would at first lead one to believe that in this railway scheme he would have a load-factor of 100 per cent. The kilowatts wanted for the 19 trains I make out to be 8,650, and for the 7 trains 2,080, or less than one-third of the maximum load. Mr. Langdon takes an average of 5,000 kilowatts, but he strikes his average by taking the maximum average in every case. He says that in each train of this class he has taken it as a loaded train, whereas some would certainly be light trains. He also accords to each their full merit of speed. The average number of trains passing Luton is 11·9, and passing Harpenden 12·4. He has taken an average of 14 trains per hour. 5,000 kilowatts will not drive the 19 trains at their full speed. The units generated per annum he makes out would be 43,800,000. That is taking 5,000 kilowatts for 24 hours and 365 days. I think the fairer way of getting the total units likely to be generated would be to take Tables II. and III. on pages 129 and 130, and work out the units per hour throughout the 24 hours. If this be done, the figure is more likely to be 39,000,000. If the units are less, and as low as I calculate them to be, it affects the cost per kilowatt-hour, and consequently per train-mile, by fully 10 per cent. in every case except the coal bill. All the other items making up the cost per kilowatt-hour are per train-mile, are standing charges, and are quite independent of units generated. As a matter of fact the load-factor, on such a scheme as is before us, will only work out at something like 65 per cent., *i.e.*, the ratio of the units which would be generated, if the maximum load 8,650 kilowatts remains on for 24 hours throughout the 365 days, and the actual units likely to be generated. Further, I do not think that the engineer in the station is likely to know when the maximum load would come on, and consequently he would require to keep the maximum power running, in case it did come on. The annual coal-bill of the Liverpool Overhead Railway, including carting and ashes, is stated as 0·118 per kilowatt-hour. Even if allowance is made for a lower number of units per annum, the cost per train-mile is fully 1¼d. in favour of electric driving. Mr. Lackie.

There is one other thing which I would like further explanation of, and that is the 2½ per cent. allowed for leakage. It would appear that the insulation per mile of the line was only something like 180 ohms.

Towards the end of the paper Mr. Langdon discusses the adoption of electric traction on small branch-railways, and incidental use of gas plant. I quite agree with him that there is a very large field for the use of this, as the cost per horse-power hour by using gas on plant not exceeding 400 H.P. is one quarter of that when using coal and steam. Further, in the small branch-lines, the whole plant could be shut down, as the stations are during the night. For small plant, therefore, gas engines would be preferable. Fluctuations in pressure are not of serious account.

Mr. M. B. Field: I read Mr. Langdon's paper through several times, and each time I did so the more dissatisfied I was with the results he arrives at. In my opinion Mr. Langdon's figures from beginning to end are at fault. He has attempted to imitate the traffic over a Mr. Field.

Mr. Field. certain section of the Midland Railway, but, in doing so, has assumed only about half the trains there should be, and has made up his total in quite a different proportion from that existing over this section. Next, his choice of the electric system appears to me to be not necessarily the best. The items of the cost per train-mile deduced by him appear to me very doubtful; and lastly, the comparison itself of the assumed electric system with the existing system seems unfair, as the two systems are not at all on the same basis. These points I propose to go into a little more fully. Looking at Table IV., I am inclined to think that a great mistake has been made. The second and third columns show the number of trains of different classes that pass Luton and Harpenden in 24 hours, giving averages of 11·9 and 12·4 passing per hour the two places respectively. On page 133 the author tells us he has taken 14 trains passing per hour a particular point, and has apportioned them:—

3	trains,	speed	50	miles per	hour.
2	„	„	32	„	„
4	„	„	35	„	„
5	„	„	25	„	„

These are tabulated in column 4 of Table IV. The author then tabulates in columns 7, 8, 9, and 10, the load, tractive effort, mechanical horse-power, and equivalent in kilowatts corresponding to each train. Columns 11 and 12, headed "Total Mechanical H.P. and K.W.," are obtained by multiplying the number of trains of each class by the corresponding figures in columns 9 and 10, *i.e.*, the mechanical horse-power and kilowatts per train. Evidently this can *only* give the total kilowatts required to propel all the trains that pass a given point in one hour.

But later on, on page 135, the author assumes that there are only 14 trains on the 50-mile route, viz., 3 to each of four sections, and 2 to the fifth section.

But with 14 trains going at an average speed less than 50 miles per hour there clearly cannot be 14 trains passing a particular point of the 50-mile route every hour. Refer again to Table IV., and assume trains of classes 1, 2, 3, and 4 run at their respective speeds for 24 hours *without stopping*, backwards and forwards over the 50-mile course:—

In 24 hours	2·8	trains Class	1	would pass	Harpenden	67	times.
„	2·66	„ „	2	„	„	41	„
„	4·66	„ „	3	„	„	78	„
„	9·3	„ „	4	„	„	111	„
	19·42					297	

Therefore in 24 hours with 19·4 trains there would pass Harpenden 297 trains, giving an average of 12·4 trains per hour. And assuming 14 trains pass a given point per hour, and the train stops at stations, there could not be less than 25 to 30 trains at one time on the 50-mile route, or approximately double that allowed for in the paper. This would not be of great consequence had the author taken the right pro-

portions of the different classes of train, but he has not done so. The proportions are :— Mr. Field.

(1)	3	as against	3
(2)	2·85	"	2
(3)	5	"	4
(4)	10	"	5

This appears to me to throw the whole Table IV. and subsequent calculations wrong. The point is that the author appears to have assumed that because, say, 5 trains of class 4 pass a given point of the route per hour, that there are only 5 trains altogether of this class on the route. This cannot be, unless they run at 50 miles per hour. Before leaving Table IV. I would like to ask what is really meant by so much horse-power *per hour*, or kilowatts *per hour*, horse-power per train-*hour*, *hourly* output of so many kilowatts ; and on page 133, why, because 14 trains pass per hour a particular place where there are four roads, is one justified in saying that there are 3·5 trains per mile per hour, per line of metals? This I cannot follow.

I will not stop to criticise the tractive effort assumed by the author for the different trains, though it appears to me to be very inadequate ; but will assume that 5,000 kilowatts will work 14 trains travelling at their respective speeds a total of 480 miles per hour, backwards and forwards on the 50-mile route.

Look at Table VII. We can divide the total cost into three main heads—

Generating and Distributing per train mile		2·11d.
Locomotive drivers and assistants	"	2·65
Renewal of machinery, cable, etc.	"	2·26
		7·02d.

2·65 pence per train-mile for driver and assistants is equivalent to 0·25 pence per kilowatt-hour, see Table VII. Now suppose these men work *only* 8 hours per day, *i.e.*, for the 14 locomotives, we should want 84 men who get 0·25 pence per kilowatt-hour. Compare this with Table V., the wages paid to the men looking after the machinery supplying these 14 locomotives. There are :—

1	Chief Engineer at	... ...	£200 per annum
1	Assist. do. "	... ...	250 " "
5	Do. do. (for sub-stations) at		200 " "
3	Switch men at	... ...	150 " "
? 15	Do. "	... ...	140 " "
1	Clerk "	... ...	120 " "
7	Engine Attendants at	... ...	40s. per week
7	Do. do. "	... ...	35s. " "
12	Stokers "	... ...	30s. " "
15	Labourers "	... ...	22s. " "
	Other Sub-station wages at	...	£2,400 per annum

Mr. Field. There are wages allowed for at least 84 men here, and by Table V. the total cost of these wages per kilowatt-hour comes out 0·0544d., whereas for the 84 locomotive attendants Mr. Langdon gives in Table VII. 0·254 pence per kilowatt-hour, or nearly five times as much. If we are to account for this by the fact that other locomotives are standing idle ready for use, it means practically that 4 squads are idle for every one on the move, and this for every hour of the day and night. This is incredible. Look at this another way. Each locomotive travels $\frac{479}{14}$—34 miles per hour, and each squad (if only working 8 hours per day) would cover 1,900 miles per week. The combined wage of the two locomotive men would be 80s. per week, which comes out at ½d. per train-mile instead of 2·65 pence; hence it is that more than 4 squads are paid for each one that is on the move. In the footnote on page 139 Mr. Langdon shows that 2·65 pence corresponds to a daily mileage of from 45 to 58 miles; how, then, can he apply it to his case where his hourly mileage is 34 per running locomotive, or, if we take two idle locomotives for every one that is moving, a daily mileage of 270?—unless he can show that in the case of the electric locomotive some abnormally great expense, which is not at all obvious, is likely to come in here. Surely some explanation of this figure is needed; it cannot include cleaners, coal men, tube men, repairs, etc., for these are given as independent items in Table VI., but it is hardly possible that it stands for the wages of drivers and assistants alone. In any case it appears to me that a comparison of costs worked out for a more or less hypothetical case where the daily mileage per locomotive would lie between 270 and 300 with those of the Midland Railway, where from Table I. we see the mileage for 1899 was but 52 per locomotive per day, cannot be of very great value. Now come to the third heading of the total cost, viz., repair and renewal of machinery, etc., at 2·26d. per train-mile. The author assumes 2d. per mile for the renewals and repairs of everything except cables and third-rail, this being one-fifth less than with steam, because he says the wear and tear of stationary engines or motors cannot possibly be as great as with steam locomotives; and with these words he practically dismisses an item which is one-third of the total cost per train-mile. Now we have to compare the wear and tear of stationary engines, boilers, economisers, condensers, exciters, switchboards, buildings, sub-stations, transformers, rotaries, cranes, chimney stacks, and electric locomotives, with that for steam locomotives alone; and I must say that the above conclusion does not appear at all obvious to me.

According to my reckoning the sum of 2·26d. per train-mile comes out at about 6¾ per cent. of what seems to me would be the first cost of a complete 10,000-kilowatt generating station, plant, with locomotives; if, however, more spare plant be allowed for, as seems to me to be desirable, the sum allowed for depreciation, renewals, etc., would come to something like 5 per cent. of first cost, which, since it has to include the wear and tear on the third rail besides the heavy expenses for upkeep of locomotives, certainly appears insufficient. Although Mr. Langdon gives the total average saving effected by the employment

of electricity on page 141 to six significant figures, I notice that on page 147 he is willing to knock off 20 per cent. of this for shunting operations, and to duplicate the generating units if necessary with a corresponding increase of his figures. Mr. Field.

I would like now to add a few words on the electrical side of the question. Even here the question is never raised as to whether the assumed system is the best for the purpose. In my opinion it is questionable whether the proper system would not be to employ three-phase motors on the locomotives. The distance between stations is great; the speed between stations might be maintained constant and the same for each class of train; then, would it not then be feasible to have a 15,000-volt transmission line (if abroad, an overhead line) and feed into the line through static transformers at intervals, transforming from 15,000 to 1,000 or 2,000 volts; the overhead trolley or other overhead contact system to be fed at this pressure, and the locomotive motors to be wound likewise for this pressure? If this system were feasible, the sub-stations with their engineers and rotating machinery would be replaced by transformer chambers requiring no attendants, the loss in the rotaries reckoned here at 10 per cent. would be eliminated, the rail loss of 10 per cent. would be replaced by an overhead conductor loss of, say, 4 per cent., and the losses in transmission line and transformers would be reduced. In fact, I think an improvement of 20 per cent. on Mr. Langdon's overall efficiency would be possible. Continuous-current series motors with rotaries are assuredly the right thing for heavy city traffic, where distances between stations are short and speeds are proportionately high. In such cases the most economical procedure is rapidly to accelerate up to maximum speed, and then, if possible, to cut off current entirely. In such cases the speed would be never constant for a moment, and three-phase motors would therefore be most uneconomical and inefficient. Where, however, long stretches intervene between stations, constant speed may be maintained, and three-phase motors will be equally efficient as series motors. Three-phase motors would, of course, be less efficient in fogs where the speed would have to be reduced; special low-speed locomotives would be built for goods trains, and for use where shunting was carried on extensively. The adoption of three-phase motors in the locomotives certainly seems to me to merit discussion, but Mr. Langdon does not refer to it at all.

Mr. PATRICK M. BARNETT said that he had come to listen and not to speak, but he had listened with a great deal of pleasure to the discussion. He thought that it would be a waste of their time for him to make any remarks on the subject, more especially as he was neither a mechanical nor an electrical engineer. He was, however, interested in the question before them very much, and he would like to put one or two questions. Mr. Barnett.

In regard to electric traction by a conducting-rail, he could easily understand that in a subway or tunnel such an arrangement might be quite suitable and proper, but he would like to know how it would be possible in country districts. They knew that in this country there were a great many level-crossings in connection with railways, and the continuous rail could not be carried over these crossings. He would like to

Mr. Barnett. know how they were going to manage this withou breaking the electrical connection.

Another point that he would like information upon was what effect electric traction would have in the case of those working on the line. What would its effect be on the surfacemen or on the train if a crowbar was laid across the conducting and running rails?

Continuing, the speaker gave an account of a visit to a railway in France worked by an electric motor and accumulators.

Mr. McIntosh. Mr. J. F. McIntosh expressed the pleasure he had in being present and hearing the discussion, and said that, like the previous speaker, he was a mechanical, not an electrical, engineer, and would have preferred to be a listener only. With regard to the question that Mr. Barnett had asked, he thought that if Mr. Barnett had gone to the Paris and Orleans Electric Railway he would have got the information he desired. The speaker had been curious to get information regarding this very point, namely, as to how an electric engine was to get over a crossing, or do shunting, without interruption of the transmission of power. He had had the pleasure of seeing how this was done, and also of travelling on an electric locomotive which took the Bordeaux express from Quai d'Orsay to Austerlitz, a distance of 2½ miles. Mr. Barnett would have found that the power was transmitted from the ground rail to the roof of the tunnel in shunting, and that a rail was placed on the roof, so that immediately the engine leaves one line for another, it takes the power from the top.

Another point that he would like to speak about was the trouble likely to arise in the winter time in connection with snow wreaths covering the power-rail. He had been puzzled to know how snow would affect the transmission of the current from the rail to the locomotive. But he had discovered that this also could be got over in the same way as they do in France, and that was in cuttings where there were likely to be snow wreaths the rail could be elevated, so that it could be out of the reach of snow. On the electric railway in France, to which he had already referred, he could assure them that it was a very interesting experiment to him to step on to an engine which had no steam; but when the driver got the signal to start he pulled the cord, and the whistle blew in the very same way as an ordinary locomotive. This whistle he found was worked by air, a small dynamo working a small Westinghouse pump. Before the train had gone very far they were going at a speed of from 20 to 25 miles per hour, and it seemed that this speed could very easily be increased. What had struck him very much was that an incline seemed to have no effect upon the electric locomotive, and he was very much impressed with it.

Concluding, the speaker said that with reference to the discussion, he thought they had perhaps been going just a little too far ahead. They were all aware of the necessity of the supersession of steam by electricity. They knew that the coals in this country could not last for ever. He was therefore more inclined to thank Mr. Langdon than to criticise his paper, seeing that he had given them the opportunity of discussing what would be the best methods to adopt in electric traction; and without beginning to calculate the cost or expense,

he thought they ought to keep in mind the necessity of having the lines worked by electricity, and to consider the best way by which this could be done. Mr. McIntosh.

Mr. SAM MAVOR: In Table VII. the largest item by far is for drivers and assistants, and it is not clear that so high an allowance as 2·65 pence per mile is necessary. I have learned from Mr. McIntosh, of the Caledonian Railway, that a fair day's mileage for a driver is from 60 to 120 miles, but sometimes 130 miles is performed. Assuming an average of 90 miles per day, and a cost of 15s. per day for driver and assistant, the rate per mile would be 2 pence. There can be no doubt that a greater daily mileage would be realised from the drivers with electric- than with steam-locomotives. The electric locomotive depôts being close to the terminal stations instead of several miles distant from them, as is frequently the case, would save drivers' time both at the beginning and end of the day's work, and the time of the driver going to or from the depôts or water towers for coal and water would be saved with the electric locomotive. Mr. Mavor.

The section of the line upon which the paper is based is favourable to the case for electric driving, as the load-factor is good, and it is doubtful whether Mr. Langdon's assumption would be realised that approximately similar results would be obtained on branch-lines. The splitting up of trains and giving more frequent service, although it improved the load-factor, would largely increase the cost for drivers. It is interesting to note in this connection that the tendency on main-line trains is to increase their length and weight. Such luxuries as dining-cars, now so common on express trains, could not be afforded unless trains were long, and the additional space provided for the comfort of passengers has led to the use of the larger and heavier coaches now employed. The section of line considered in the paper is approximately level, but on other sections of the Midland, and on the London and North-Western, and on the Scottish lines, steep gradients have to be faced, and this, coupled with the increasing weight of express trains, would involve the use of electric locomotives of much greater power than those anticipated in the paper.

Mr. W. PICKERSGILL: In computing the total power required to work the train on the given line between St. Pancras and Bedford, Mr. Langdon has taken for the basis of his calculation the number of trains passing a given point in a given time. I am of opinion that a more accurate result of the power required could have been obtained if the maximum load to be hauled at an average speed at one time had been taken for the whole of the 50-mile line. Generally speaking, the maximum number of trains that can be put upon a length of line depends upon the number of block sections, and assuming that there are 10 block sections between given termini, it would be possible to get as many as 40 trains in a 50-mile section of four rails at the same time. This, however, is very improbable, but I am of opinion that during holiday seasons or specially heavy traffic there would be many more trains on the section than 14, which is the number that Mr. Langdon bases his power upon. If this were so, it would be found that in order to provide for the maximum demand, as also to insure Mr. Pickersgill.

Mr. Pickersgill. against breakdowns, and have duplicate plant for repairs, a larger installation would be required and consequently increase of capital, which would have the effect of increasing the standing charges and the cost per train-mile.

I am of opinion that the formulæ adopted by Mr. Langdon for the traction effort for moderately high speeds, viz., $3 + \frac{V^2}{250}$ pounds per ton is not far from being correct, but I find that no allowance has been made for the resistance due to gravity, curves, or head and side winds which offer very serious resistance to the passage of trains, especially when running at high speeds.

If the data as to the cost of working a train-mile by steam locomotive includes the expenses due to piloting, light running, and shunting, and other work not classed as train-miles, then the comparison as to the cost of working by electricity, not being on the same basis, is fallacious, and it would be advisable to get a true comparison before seriously discussing the question.

I should also expect that the average cost per train-mile for steam locomotive also includes a large amount of heavy suburban and local goods working through some of the busy districts on the Midland line, and the cost of working these trains would no doubt be very much higher than the cost for working trains on the main line. If these trains, which can hardly be considered as main-line trains, and also the cost of working them, were eliminated, it would no doubt have the effect of materially reducing the cost per train-mile for the section under consideration.

I observe that Mr. Langdon allows a sum of £50,000 per annum for the whole of the shunting on the Midland Railway, but I am of opinion from experience that this sum must have been far too little to cover the cost, considering the magnitude of the work on the Midland Railway, to say nothing of the piloting and light miles and other work not included in train-miles.

Mr. Yorke. Mr. R. F. YORKE (*communicated*): I have only just received to-day a complete printed form of the paper, and am therefore rather handicapped in entering into a discussion on it at such short notice.

It has been printed by the electrical papers, but in some cases errors have crept in, such as that concerning the pressure which was stated to be 100,000 volts instead of 10,000; and the paper itself for publishing purposes has been split up into two different parts. I should like to take this opportunity of appealing to our electrical press, whether they could not in important papers of this kind print the whole in one issue. It is most tantalising, on arriving at the interesting part, to have to wait another week for the conclusion.

It is a great pleasure to me to see my former chief of the electrical department, Midland Railway, again to the front. He was at the front in the early days of electric lighting, not only as regards the electric lighting of the Company's hotels, but in lighting the goods and shunting yards, which entailed a subsequent diminution in the risk to life, and many other contingent advantages. Mr. Langdon is now again to the fore with his present proposal for substituting electric locomotives in place of those worked by steam.

Mr. Yorke

The present time does not appear opportune for discussing engineering details. Provided the railway companies accept the principle, there is any amount of electrical engineering talent in this country successfully to evolve the best system to be adopted. This system must be applicable to all the railways, so that such errors as those which occurred in connection with the broad and narrow gauge may be avoided.

There are, however, one or two general points which I should like to notice. The first is this: that assuming electric working be introduced, the public will certainly expect that trains will be run at an increased speed. It will be quite possible to do this, using the existing weight of rails, as the injurious knocking action of the reciprocating engine will be absent.

The other point I note is that the author has taken as the basis of calculation the working of an important main line; but how do the figures work out for branch lines with only a comparatively light passenger traffic? Will it be possible to work these lines also economically? I am interested in this question, as I have lately had occasion to lay a proposal before one of the Scottish railways for working a short line electrically by means of water power, and the question to be decided was whether, in view of the small traffic, it would pay to put down the necessary plant. Even supposing that the railway companies do not accept the proposal in its entirety, I still think that our Highland railways would benefit by the adoption of auxiliary electric locomotives for working their steep gradients. Where these heavy gradients exist, water power is nearly always present. Take the Highland Railway, for instance, with the steep climb from Struan to the top of the Grampians. The river Garry would furnish any amount of power for auxiliary locomotives.

Again, on the West Highland Railway, with the long climb from Spean Bridge up to the summit at Corrour, the water power of the Spean Valley could provide some 10,000 H.P., which would be greatly in excess of what would be required.

I agree with the author on one of the points on which he lays stress, namely:—that the new system can be introduced by degrees, and when it has been proved to be a success, further great extensions will necessarily follow.

At the conclusion of the meeting, Mr. H. A. Mavor moved "that Colonel R. E. Crompton and his gallant boys, who are being officially welcomed back from the front in London by our Parent Institution on Tuesday next, be accorded a hearty vote of congratulation by this Section, and that we send them our sympathetic wishes on the conclusion of their patriotic and arduous campaign."

This was duly seconded, and was carried with acclamation.

Mr. Pickersgill.

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REPLY OF MR. LANGDON TO THE DISCUSSION ON HIS PAPER: "THE SUPERSESSION OF THE STEAM BY THE ELECTRIC LOCOMOTIVE." (*London, December 6th*, 1900.)

Mr. Langdon.

Mr. W. LANGDON, in reply[1]: It is perhaps unnecessary that I should say that the paper which I have submitted for your consideration is practically the outcome of the success that has attended the recent application of electricity to the movement of railway trains. That which has been done has shown the practicability of the application of that power to the purpose, and naturally the question arises whether any and what economy might be expected to attend its use, supposing it should be found applicable to the same purpose in connection with our large railway systems. I have been attacked because I have brought this paper before the members of the Institution of Electrical Engineers. Well, it naturally appeared to me that it was a question which intimately affected the Institution of Electrical Engineers, and that perhaps no better body in the kingdom could be found to discuss its merits or its de-merits. It is not improbable that some of my deductions may be erroneous, although I have endeavoured in considering the subject to deal with it in an unbiased manner and as fairly as possible. I do not suppose that if electrical energy is applied, as undoubtedly it will be applied some day, to the movement of the traffic of the main lines of railway of this kingdom it will be in my time; I may see something of it, but I shall not see its general application. I have therefore no personal interest in the subject beyond the advancement of that which I believe will prove of vast interest to the community at large.

Professor Forbes has stated it is a paper which ought to have been brought forward somewhere else, and he has in a measure criticised my deductions. As I have stated in the paper, the subject has necessarily been dealt with by me in an abstract manner. The purpose of the paper has been to evolve, if possible, some result as to the economy and other advantages that might attend the use of electricity as applied to our large railway-services, and it certainly appeared to me that there was much more probability of a successful issue if applied on portions of line where the line was considered to be full of trains and where there was a great deal of work doing, than if a section of line less used were selected. It was for that reason that I took the London and Bedford section of line. I do not know if I am wrong in the tractive effort formula which I have employed, but I do know that it is derived from absolute experiments. I am not, however, prepared to say if it embraces actual results obtained from goods and mineral trains, but I have every confidence in its accuracy with respect to all kinds of passenger trains.

Mr. Mark Robinson, on the occasion of the last meeting, raised the

[1] The first portion of this reply was given verbally at the Ordinary General Meeting in London, on Thursday, December 6th (see p. 193).

question whether it was preferable to work a section of line from a central generating station serving several substations or to work it from a number of local generating stations. I feel quite satisfied that his remarks were *bonâ fide*, that they were not at all influenced by any personal desire with respect to the type or capacity of stationary engine which should be employed. Messrs. Willans and Robinson had in the Paris Exhibition an engine of some 1,400 H.P., I think, and I have no doubt that if they were called upon to produce an engine of still greater capacity it would be quite within their power to do so ; but that which has, I think, escaped the attention or consideration of several who have taken part in this discussion has been the fact that with a central generating station serving substations you are able to transfer the sectional load from one section to another without materially altering that at the generating station. Mr. Langdon.

Mr. Raworth has called attention to the fact that although I had taken 14 trains as the average number of trains passing over the section of line in one hour, one of the tables produced in the paper showed that as many as 19 trains were present during one of the 24 hours. That is a fact, but Mr. Raworth omitted to say that during other hours the number was considerably less, the minimum being in one hour as few as seven. That shows how the load will vary. There will be a continually varying sectional load so far as the subsections themselves are concerned, but the load at the central generating station will be practically continuous. If you have to establish local generating stations, of course you have to make provision for the maximum number of trains that would be in that section, and your power must always be there in order to give the possible maximum output. That means you would have to increase your plant, and as your load would not be constant as it is at the large central generating station, you could not effect the same economy especially with regard to your coal bill. I have since the last meeting gone into some figures with respect to the establishment of these local stations, and I make the primary outlay £430,000, instead of £470,000 for the central scheme, while the working expenses come out at 0·8233 per kilowatt as against 0·6726 for the central generating station, and per train-mile at 7·160 against 7·021. If we add to that interest at 3½ per cent. on the outlay, we get this result : 0·9223 per kilowatt for the local generating stations as against 0·7716 for the central station scheme ; and 8·0208 as against 7.662 per train-mile. In making that calculation I have taken coal at 4 lbs. per kilowatt, because it seems to me quite clear that you could not maintain 3 lbs. with so varying a load.

The subject as to whether a section of line could be worked more economically or with greater advantage by a central station feeding so many substations, or whether the line should be divided into sections, each section being provided with its own generating plant, is one which would naturally command careful consideration at the hands of any one who might be called upon to consider its practical application.

It has been stated that my allowance of 3 lbs. of coal per kilowatt is insufficient. Mr. Cunningham, on the occasion of the last meeting, quoted 3·6 lbs. as the lowest he was aware of ; Mr. Parsons suggested 2·5. Only a short time since, *Engineering* published some data upon

Mr. Langdon.

the subject, and I have culled one or two results from its pages. On the Metropolitan Elevated Chicago line the lbs. coal per kilowatt was 1·75; at Boston it varied from 2·61 to 4·13. I have not here the whole of the figures, but if my memory serves me right there were several results given with respect to Boston, and the average came out at a little over 3 lbs. Baltimore City was 3·23 lbs., and Brooklyn City 3·0. Again, the *Engineer* of May 25th, dealing with the Berlin tramways, gives 2·1 as the amount of coal used per kilowatt-hour with super-heated steam, and 2·3 with saturated steam.

My station charges have not been in any way criticised, but the cost of drivers has been mentioned by more than one speaker. Mr. Crompton considers that a less wage might be paid to the class of drivers who would be required to handle the electric locomotives or motors. Possibly that would be so. I have not claimed any exception for that, but, on the contrary, I have in all my charges, as I thought, endeavoured to deal with them in such a liberal manner that they should merit no adverse criticism. There is no doubt that the cost of drivers is a very heavy charge indeed, but I do not see how it is possible to have it to any extent modified unless the traffic arrangements are also modified. With regard to the repair and renewal of machinery, Mr. Crompton very properly pointed out that there would be no boilers practically beyond those required at the generating stations, and that consequently there should be a great reduction in the annual cost, because a great deal of the charges for repairs in connection with the locomotive is in connection with the boilers. He considered—and I think one or two other speakers who followed him also considered—that my charges in connection with the repair and renewal of machinery were too high, and that something less than twopence per train-mile ought to be obtained. In this I quite agree, but I prefer to adhere to the figures I have adopted for the reason just advanced.

Professor Carus-Wilson has been kind enough to send me a copy of his paper on polyphase traction, read before the members of the Institution of Mechanical Engineers. I readily and heartily acknowledge the Professor's kindly courtesy, but I may perhaps be allowed to say that whatever is done with respect to the introduction of electricity for the operation of main-lines of railways it will have to be, I feel convinced, of the most simple possible character. For instance, polyphase working would require two contact rails, and that alone would introduce a great deal of complication.

I am sorry to find that time forbids the completion of my remarks. I will endeavour to complete what I was desirous of saying in writing.

Mr. W. LANGDON (*communicated January* 23, 1901): The lateness of the hour, and consequently the few moments which could be allotted me in which to attempt to reply to the observations of the several speakers, obliged my remarks to be so hurried, and so incomplete, that I feel it will be necessary to trespass somewhat largely upon the privilege accorded me to supplement what I then said by this communication.

It is not my intention to review the remarks of each speaker, but to deal with the salient points under their respective heads. These I regard as—

Mr. Langdon.

(1) The Tractive-Effort formula employed by me ;

(2) The Coal factor ;

(3) The Hypothetical Electrical System employed for comparison. And to these I propose to add certain observations emanating from myself in relation to—

(4) The Rolling Stock and Permanent-way arrangements.

Tractive-Effort Formula.—The results arrived at under Table IV. depend largely upon the formula which I have employed. If inaccurate, or affording too low a factor, my deductions will call for modification. The question therefore is whether the formula employed is a reasonably

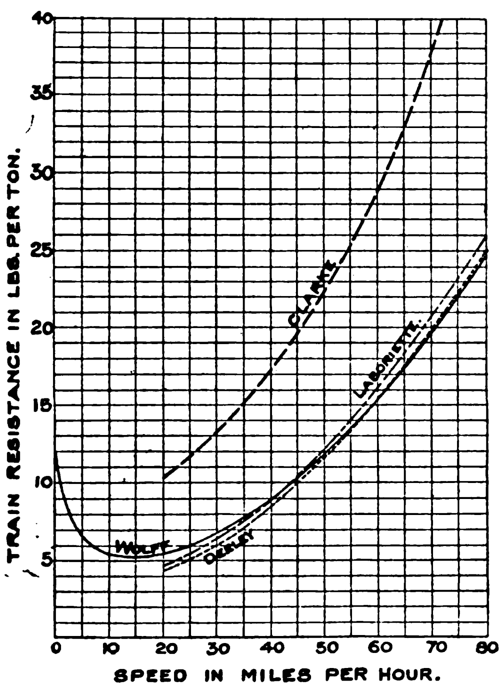

FIG. C.—Extracted, by permission, from Fowler's "Mechanical Engineer" Pocket-Book for 1900.

fair one. By the courtesy of Mr. W. H. Fowler, the author of "Fowler's Mechanical Engineer Pocket Book for 1900," I reproduce the Chart which occurs at page 333 of that work, showing the Tractive Effort curves plotted from results arrived at by various experimenters. Wolff's curve is derived from data published in the *Mechanical Engineer for* February 25, 1899, and is as follows :—

$$R = 3\left\{\frac{V + 12}{V + 2}\right\} + \frac{V^2}{300};$$

Mr. Langdon.

R being resistance in pounds per ton, and V velocity in miles per hour.

This formula when worked out for a speed of 50 miles per hour provides a lb.-ton factor of 12. That adopted by me provides for 13 lb.

At page 138 Fowler also furnishes the following formula for speeds over 20 miles an hour as that established by "modern experimenters":—

$$R_1 = 3 + \frac{V^2}{290};$$

and where the speed is less than 20 miles an hour—

$$R_1 = 3\left(\frac{V + 12}{V + 3}\right) + \frac{V^2}{300}.$$

R_1 in each case being resistance in pounds per ton of engine, tender, and train; and V speed in miles per hour.

In each instance these afford a lower lb.-ton factor than that employed by me.

Laboriette's curve is a trifle higher than Wolff's, while Wolff's and Deeley's are practically synonymous.

I here insert a letter which I have received from Mr. Deeley.[1] Mr. Deeley, as is well known, occupies the position of Mr. S. W. Johnson's Chief Technical Officer, and has for many years been associated with investigations of this character.

On the chart, copy of which I have produced, is a curve representing Clark's deductions; and in "Molesworth" is the formula—

$$R = 6 + \cdot009\,V^2;$$

where V = Velocity of train, miles per hour, R = Resistance, lbs., per ton of train, which, according to a footnote, is said to be "modified for oil lubrication, from D. K. Clark's formula $\frac{V^2}{171} + 8$ for lubrication by grease." (The name is spelt differently, but the curve is apparently based upon the above formula.)

Working these out for the same speed, viz., 50 miles per hour, it appears that the modified formula—presumably intended to apply to oil lubrication—produces a lb.-tonnage of 28·5, while that assumed to be applicable to grease lubrication affords a result of 22·62 lbs.; indicating that the lubrication by grease is superior to oil lubrication, an opinion which few will, I think, share.

"Molesworth" also gives a formula by Harding, stated to be inapplicable to low speeds. By this formula the table which accompanies it shows that for a speed of 50 miles the lbs. ton is, by experiment, 32·9, and by formula, 35·3.

Summarised, I classify these with their results as under:—

[1] Printed in Report of Meeting of Glasgow Local Section (see p. 200).

Mr. Langdon.

Deeley	All agreeing in practically	$3 + \frac{V^2}{250}$	Lbs. Ton at speed of 50 miles per hour. 13·00
Wolf			
Laboriette			
Barbier } Quoted by Deeley			
Du Bosquet }			
Fowler		$3 + \frac{V^2}{290}$ ...	11·62
Do. (for low speeds)...		$3\left(\frac{V + 12}{V + 3}\right) + \frac{V^2}{300}$ ...	11·84
Clark (modified)... ...		$6 + {\cdot}009\ V^2$ ...	28·50
Do.		$\frac{V^2}{171} + 8$ ...	22·62

It is not clear that Clark's formula embraces the weight of the engine and tender. If so, then the H.P. required for a train of 275 tons, including engine and tender, when travelling at a speed of 50 miles an hour, would be, by formula, $6 + {\cdot}009\ V^2$, 1045, instead of 477 as shown by me. If it is not intended to embrace the engine and tender, then the H.P. would be 703. In the first case a doubtful attainment on the part of the locomotive, and, in either case, excessive. Indeed the results appear to be such as to favour the impression that the higher formulæ must be the result of experiments conducted under conditions very different to those attending the tests carried out by other experimenters.

As somewhat confirmatory of the result worked out by me it may, perhaps, not be out of place to quote, from Mr. Johnson's Presidential Address already referred to, the following sentence in reference to a train of 256 tons: "One of my single-driving-wheel locomotives, running between Nottingham and London, burns per indicated horse-power per hour, from 2·9 to 3·1 lbs. of coal with ordinary firing, and uses about 29 lbs. of water per horse-power, per hour, when the *mean* indicated horse-power is about 400." The italics are mine. From this I presume it may be inferred that 400 H.P. is the mean indicated power exercised during the journey. The horse-power for such a train and speed is shown in my Table IV. as 477.

Although a copy of my paper was sent to the General Managers and the Locomotive Engineers of all the chief railways, Mr. Pickersgill, of the Great North of Scotland Railway, is the only locomotive engineer who has referred to the subject, and, as I read Mr. Pickersgill's remarks, he regards the formula as fairly correct, but considers certain allowances for curves, gradients, etc., have not been made. The formula is the result of a large number of experiments with ordinary made-up trains, and, so far as I can ascertain, does take into consideration all these points as well as acceleration. As Mr. Pickersgill has, in conformity with others whom I have quoted, made numerous experiments to get at absolute results, and as his results would appear to agree with

Mr. Langdon.

those obtained by the majority of other experimenters whom I have quoted, as well as with that formula which I have employed, I can see no reason for any modification of my figures—especially as Mr. Pickersgill's investigations would appear to have extended to goods as well as passenger trains. It should, however, be borne in mind, as I have indicated in the paper, that my deductions are framed on a clear run by the trains at the speeds indicated. Some allowance may be necessary for frequent or exceptional acceleration, but it is not proper to base this upon data obtained from "omnibus" traffic such as that of the City and South London, the Metropolitan, or other subway trains. With such a central generating scheme as I have outlined, very much of the demand for acceleration would be met by the cessation of demand due to trains moving under momentum prior to stoppage.

Coal Factor.—Probably the item next in importance as affecting the accuracy of my conclusions is that of the coal bill. It has been argued that the whole question of economy centres upon the coal consumption. No doubt coal is a large factor, but I do not agree that it dominates the issue. The question is whether, with a continuous output, day and night, with a load factor closely approaching 100 per cent., it is possible to generate one thousand watts of electrical energy, for one hour, with 3 lbs. of coal—coal of an ordinary character, such as is known as Yorkshire or steam coal.

In dealing with this branch of the question at the conclusion of the discussion, I quoted some cases in which electricity power stations had complied with this condition, but being pressed for time I did not give the load factors. I do so now.

	Output.		Coal per Kilowatt-hour.
Metropolitan Elevated Railway, Chicago	2,070,537 kw.	...	1·75 lbs.
Boston (1897):—	Load Factor.		
Albany St. Central	34·8 per cent.	...	2·86 ,,
East Cambridge	52·2 ,,	...	3·24 ,,
Dorchester	33·6 ,,	...	2·48 ,,
East Boston	22·3 ,,	...	3·18 ,,
Charlestown	46·4 ,,	...	2·61 ,,
Allston	47·0 ,,	...	4·13 ,,
		Average	3·083 ,,
Brooklyn City Railroad (1897):—			
Kent Avenue Station	36 ,,	...	3·0 ,,
Southern Station	30 ,,	...	3·5 ,,

The whole of these generating stations have not a continuous output. They are shut down, or the fires are banked for some hours out of the 24; while it will be seen that the load factor is feeble in comparison with that which forms the basis of my calculations. I have already referred to the results obtained by the Berlin tramways power-station, viz., 2·1 to 2·3 lbs. per kw. hour, and it may perhaps not be out of place

if I here quote from a letter received by me from Mr. John Meldrum, of Manchester, who, after discussing the subject in a very full and complete manner, observes : "We should consider that the 2½ lbs. mentioned in your letter could, under the favourable conditions of constant maximum load, such as you name, be reduced in practice to 2¼ lbs. or even slightly less, of course taking the plant to be of the most modern and economical character." I am here glad to have the opportunity of thanking Mr. Meldrum for his courteous reply to my inquiries, and ready permission to make use of his letter. Mr. Langdon.

The fact is there exists no electricity generating station working under such a load factor as is possible—and probably only possible—when dealing with a demand such as would be necessary to meet the requirements of a stretch of from 30 to 50 miles of railway filled with trains both day and night, fed from a central generating plant capable of serving such a section of line by substations. The results I have quoted above do not apply to such a condition. Surely then if attained in America, and on the continent of Europe, under less generous conditions, it ought to be possible to attain it in England.

The mode adopted by me for considering the weight of coal required per kw. is a very definite one. The power derived from the electricity generator can be measured to the greatest nicety. This is not so with the steam engine itself. I freely admit I am unable to follow the figures quoted in relation to the consumption of coal by the locomotive —whether the indicated horse-power, or the per ton-load, forms the basis. I take my figures from the data given in Mr. Johnson's Presidential Address (although other and later figures are no doubt to be found in those technical periodicals which from time to time publish such details), for the reason that they are authoritative. Mr. Johnson shows that the average consumption for coal and coke for 24 years was 50·191 lbs. per train-mile, and this had been an increasing factor from 1884, the quantity for 1896 being 54·19 lbs. Now if the London and Bradford express locomotive previously quoted burns per I.H.P. per hour 2·9 to 3·1 lbs. of coal per horse-power, per hour, when the mean indicated horse-power is about 400, it is clear that such engines travelling at the speed indicated burn about 24 lbs. of coal per train-mile. This means that the locomotives on other trains burn *considerably more* than 54·19 lbs. per train-mile ; and with these figures before us it is difficult to follow the argument that steam locomotives, when standing, do not consume coal. To an ordinary observer it seems clear that much of the cost at present incurred for coal and coke is due to the consumption consequent upon trains being kept standing at stations and other points *en route.* When a train is put on one side, for another to pass, it must keep steam, or it would not be ready to proceed when called upon. My paper has not been written for the purpose of decrying the steam locomotive. I share the general opinion that the locomotive is, having regard to the purposes to which it is placed, and the conditions under which it has to work, a marvellous piece of mechanism. It is not, having regard to these conditions, an extravagant power producer, and no such suggestion has been made, but at the same time there can be no question that it is more costly than would be electric traction.

Mr. Langdon.

Electrical System.—The object of my paper was to consider, provided main lines of railway could be worked by electricity, whether such a mode of working would be attended with economy. For this purpose it was necessary to *assume* an electrical service. In this spirit I outlined a plant which I thought suitable for that purpose. Purposely I drew the efficiencies of that plant wide, nor did I attempt to crimp the staff, or other charges in connection with the working arrangements. A certain sum was allotted as the cost of the plant, cables, etc., and if this sum is fairly sufficient for the purpose it is scarcely material to the object in view whether the scheme outlined by me is the best that could be devised or not. I believe it would be found adequate, but it is worth while observing that any increase in the capital outlay would scarcely affect the annual charges beyond those required to cover interest and depreciation. While penning these remarks my attention is drawn to the details of the Albany and Hudson Electric Railroad—a line of some 37 miles, the electrical equipment of which is much the same as that outlined in my paper; the potential difference of the primary current being, however, 12,000 instead of 10,000. The service current is the same, viz., 600 volts. The contact conductor rail is outside the traffic rails, and is protected by timbers on either side of it, so that accidental short circuits or shocks to workmen may be avoided. The New York Manhattan Elevated Railroad is also adopting the outside position for the contact rail.

My paper was read, not for the purpose of advertisement, or to serve any personal interest whatever, but that the subject with which it dealt might be discussed, and, if shown to be in any portion erroneous, that the errors might be discovered. Having no precedent much has had to be assumed, and hence my desire that the charges applicable to electricity should not be too narrow, or that I should take into account every source of saving which would attend its use. Perhaps I am wrong in assuming that where my deductions have been questioned it would have been but fair that those who questioned them should have furnished what they believed would prove more accurate. Whether, in the event of electricity proving of service for railway work the plant I have so roughly sketched out for comparison purposes is suitable or not, there can be little doubt that neither it nor any other scheme would be accepted without very careful consideration on the part of the company about to make use of it. My effort has been to show that when the time arrives for such an investigation it may, from an economical and national point of view, be undertaken with every prospect of advantage.

The remarks of Mr. Mark Robinson with regard to the power of the steam unit to be used, and his observations on fast *versus* slow speed engines, will be read, I am sure, with much interest. His observations on the propriety of working the section of line by five local generating stations, rather than by five substations served from one central generating station, merit every consideration, although, personally, I regard the scheme suggested in the paper as in many respects more advantageous. My verbal remarks on this point were so hurried, that I feel I failed to do justice to the economical advantages which should, it appears to me, attend a central and substation scheme.

Mr. Langdon.

These lie almost entirely in its flexibility. A variable load in the sub-sections affects very little, if at all, the output from the generating station. The generating station has to meet the *whole* demand, and if this demand is centred all in one sub-section, or distributed equally throughout the whole of the sections, it is, as a load-factor, immaterial. In the case I take, that load is the 14 trains per hour. The load being, so far as the generating station is concerned, fairly constant, there is no waste in coal, water, or labour. Local generating stations would effect a saving in high-tension cables and in transformers, but the equipment of each station would be more costly; for each station must have at least a spare set of generators, and unless each 10-mile section so served were filled with trains, so as to establish a constant demand, the result would be a much lower load-factor. The capital outlay would probably be less, and the electrical efficiency would be higher. A number of short sections thus locally served would possibly afford greater security against failure of machinery, but it would be at the cost of economy. All these are points which will necessarily demand attention when an absolute proposition is ripe for consideration. The governing factor should, to my mind, be the *load-factor*—such a section of line as would insure a constant output.

Attention has been directed to the advantages of polyphase systems. A polyphase system would appear to be objectionable. In the first place, because it would entail the use of two conductor or contact rails which, at junctions and crossings, would prove extremely difficult, if not quite inadmissible; and in the second place, on account of its speed-rigidity—its inability to admit of acceleration of speed. Railway companies have for years been gradually increasing the speed of their trains, and any electrical system that may come into use must be such as will admit of this acceleration if called for, and also afford as large a diversity of speed in the movement of trains as is at present enjoyed. A mixed traffic has to be dealt with, and this cannot be disregarded. A passenger train differs from goods and mineral trains in that each vehicle is supplied with brake-power which enables the train to be stopped, if necessary, practically in its own length; the brake-power of goods and mineral trains is, however, limited, and they can only travel at a speed regulated by the command which the brake can exercise. Climatic conditions largely affect the speed and operations of trains on overland railways. In dense fogs all traffic becomes congested, and the movement and speed of the trains has to be subordinated to the conditions which prevail. A predetermined speed, which must be rigidly observed, would, I fear, entail difficulties.

Rolling Stock and Permanent-way Equipment.—It was with some surprise I heard Mr. Sprague comment upon the difficulty of producing an electric locomotive competent to deal with such loads as are indicated under Table IV. The more so as I had in my mind an electric locomotive built by the General Electric Company for the Baltimore and Ohio Railway Company, for the purpose of dealing with heavy traffic. I believe I am correct in stating the details of this locomotive to have been announced as follows:—Weight on driving wheels, 96 tons. Draw-bar pull, 42,000 lbs.; starting ditto, 60,000 lbs.

Mr. Langdon.

Diameter of driving wheels, 62 in. Length overall, 35 ft. Propelling power 4 motors, each rated 360 H.P.

It is quite true that large electric locomotives have not been built to travel at speeds of 50 miles or more, but I believe this to be simply because there has not been a demand for them. Electricity where employed for railways has not been used in what may perhaps be termed bulk; it has been confined to comparatively light trains—the largest and heaviest locomotives employed in England being those of the Central London. And in all these it is probable that the use of a heavy locomotive has, for obvious reasons, been rather shunned than encouraged. One would imagine that no difficulty in ventilation, construction, or speed would attend the production of whatever is required so long as it does not exceed in space the structure gauge of the railway upon which it is required to travel, and as it does not exceed the safety impact allowed for the structures over which it has to travel. Main overland railways have a permanent way far less liable to the effects of vibration than underground lines.

Some stress has been placed upon the propriety of applying the motors to the carriages instead of employing an electric locomotive. Main-line traffic, embracing goods and mineral trains, can only be worked by the latter.

It is, as I intimated in the concluding portion of the paper, in the arrangements to be adopted for the distribution and collection of the current that the greatest difficulties will be encountered. No doubt, had time admitted of the continuation of the discussion, reference would have been made to this branch of the subject. As it is, the matter has passed unobserved, and yet in it, so far as can be seen at the present moment, there is cause for the greatest consideration. Hitherto, where electric energy has been the power employed, it has been conveyed by overhead conductors, or where a contact rail has been used, it has been in those cases only where the line of railway is not open to trespassers. With overland railways the intrusion of irresponsible people can no more be insured against than rain, snow, or flood. With all large railways an overhead conductor, or a structure for the purpose, is, it is to be feared, impossible. If the current has to be collected from a conductor on the ground, it appears that the conductor must be arranged practically on the same level as the railway metals, or very little above them. It must be protected in some manner to avoid accidental, and, if possible, intentional short-circuits. Assuming that this may be accomplished, its position in relation to the railway metals next demands attention. If laid on the sleepers which carry the railway metals, difficulties will probably arise in executing repairs to the running roads. It would therefore appear desirable that it should be entirely dissociated from them. This again will necessitate the use of a flexible collector, for if the contact rail is dissociated from the sleepers which support the railway metals, it will be necessary to ensure for it a position relative thereto.

Although it has been, I believe, fully demonstrated that the current can be collected from such a contact rail at a speed of 60 to 70 miles an hour, further experiments dealing with maximum quantities of current might with advantage be undertaken.

Sections of line subject to floods could only be dealt with by raising the line above the flood level—probably not a very costly matter, and, moreover, a proceeding desirable from other points of view. Mr. Langdon.

Conclusion.—In concluding these remarks I feel it desirable that I should emphasise the fact that the purpose of this paper has been to show that, *primâ facie*, there are grounds for assuming that, when those impediments which now exist have been overcome, the contemplated change will not be attended with pecuniary loss, but that on the contrary, it may, and probably will, be accompanied by many advantages. As a step—the first step—towards this it has been necessary to compare the cost of the possible new agent with that of the present. In doing so I have drawn *two* comparisons with the cost incurred under the steam locomotive. One with the *average* yearly cost for a period of 24 years; the other with that for 1899. It is evident that in criticising my deductions the fact that my comparison was not confined to the cost for the "average" period has been overlooked. Those deductions show the assumed cost of electricity at 7·021; steam, for the average of 24 years, at 8·943, and for 1899, at 10·218 pence. Now assuming, for the purpose of argument, that the formula which has been so much discussed, but which has at last been practically confirmed, is not sufficiently high so far as it applies to goods and mineral trains, it can but affect the electrical charges to a very slight extent; it cannot, for instance, double them. But suppose the generating charges *are* doubled, there will still, in comparison with the "average" yearly cost of steam, remain a balance in favour of electricity; and of practically a penny-halfpenny per mile (or some £271,583), on the 1899 comparison, *i.e.*, without deductions for contingencies! Add to this, as has more than once been commented upon by those who have participated in the discussion, the fact that the efficiencies upon which the output of electrical power is based are low; that all trains have been regarded as loaded trains; that more than the hourly average number of trains are embraced by my calculations; that the cost of repairs and renewals, as set forth by me, are deemed excessive; and add to this many other obvious savings such as the painting of stations, the redecoration of coaches, the saving in the abolishment of isolated plants, and I doubt if there will be many who will condemn me for having overstated the case for electricity.

The position I have assumed for electricity is necessarily somewhat hypothetical. The question is, Is it reasonably fair? It has been pointed out that the electrical service has been framed to meet only the average hourly train service as ascertained by Tables II. and III., and that occasions must arise when this will be exceeded. This will undoubtedly be so,[1] but my reason for selecting the section of line indicated was that it was a busy line—a section of line that might be

[1] Since the reading of this paper I have obtained from the stations named a return of the greatest number of trains passing those points on any one day. Here are the figures :—

Luton, January 25th	... ...	297 = 12·4 per hour.
Harpenden, August 4th	... ...	331 = 13·8 per hour.

The basis taken in the paper was 14 per hour.

Mr. Langdon. truly regarded as a full line, and that it might, consequently, be looked upon as worked up to its full capacity. Obviously, however, if there were more trains—provided electricity is, *per train-mile*, less costly than steam—the greater the number of trains and consequently the greater the mileage, the greater would be the saving. It might, and probably would, mean an increased capital outlay—an increase in interest charge and repair—to be met by the additional saving on the additional mileage run.

One or two members have, in their observations, expressed some difficulty in following me in regard to the number of trains per hour which I have accepted. My calculations are based upon the kilowatt-hour for the power to be generated; upon the power shown to be required for dealing with one hour's traffic; and, for the purpose of comparing electric with the steam charges, with the train-mileage accomplished in the hour. The number of trains passing any one point on the length under observation in the twenty-four hours may surely be taken as the number for the day. I have taken two points. The number of trains was 287 in one, 297 in the other. The greater of these divided by 24 will give an average of 12·38 per hour. I have taken 14 trains, which 14 trains, as I show, should travel 479 miles in the hour. I am afraid I cannot put it clearer. I did try to collect and tabulate the times of trains passing several points, but it became too complicated to be dealt with in such a paper. Perhaps it would render my reasoning clearer if my critics in this instance would assume either of the returns as applicable to one end of the section—say Bedford. Thus for the twenty-four hours there would be 297 trains in all arriving or departing, and $\frac{1}{24}$th of this number would be the average hourly number of trains for the period.

It has been stated that the mere cost of shunting-work would more than absorb the £50,000 set apart for contingencies. Surely those who advance these arguments lose sight of the fact that much of the cost for shunting lies in the time the engine is doing no work. Should it ever transpire that the work of shunting-yards can be worked electrically, a great saving in this respect should attend it.

It is primarily to main-line working that I have addressed myself. Several speakers have intimated that electrical traction will first be employed on the branch lines. There are, no doubt, branch lines the locality of which would largely benefit by more frequent train facilities; but we have to bear in mind that the majority of branch lines have been established to secure connection with the main line, and, consequently, that the traffic thereon must be largely dependent upon the main-line service. If electricity can be employed for branch lines, why not for main lines? Presumably the only reason is the large power demand required for the latter. The electrical system employed must be identical—that which serves the one must also serve the other. Branch lines will be most economically served as a part of a main-line installation; that is manifest. Those difficulties that attend main-line working will also, although in a less degree, attach to branch-line working, and as it is in the operation of the former that the greatest advantages and economies will arise, it is towards its accomplishment that efforts should

be directed. Apparently what is required is a safe means of conveying the current to the trains, and an electric motor that shall perform the functions now dispensed by the steam locomotive. The crux of the whole question would seem to reside in the mode to be adopted for the distribution of the current. Any difficulty which will attend the determination of the site of the conductor rail, or the means for collecting the current, is not likely to prove so serious as that which will accompany the provision against vicious interference with the former for the purpose of disorganising the traffic. The subject is one which we may be sure will claim the attention of inventors. Legislation may aid, but all the powers of the law will not prove so efficacious as a means by which it shall not be possible, or, at least, by which it shall be so difficult to tamper with it as to render it not worth the risk. To protect the rail from accidental interference presents no difficulty. That may not only be done, but in the doing of it insulation may be aided. It is the malevolent action of the miscreant, and of the mischievous, which has to be guarded against. Mr. Langdon.

Mr. Alexander Siemens, in directing attention to the title of the paper, has asked how the trains hauled by the steam locomotive are to be dealt with at that point from which the traffic has to be conducted by the electric locomotive.

My paper aims at the supersession of the steam locomotive—at its replacement by the electric locomotive. No railway company would break up their time bill, or dislocate their service in the direction of Mr. Siemens' question for the purpose of introducing electricity. The electric locomotive, to compete with the steam locomotive, must be able to couple on to a train and haul it away precisely as is now done by the steam locomotive. Section by section of a railway system might then become converted to the application of electrical agency without undue sacrifice of material, and with absolutely no inconvenience to the traffic.

It has been said that economy will not prove the means by which railway companies will be induced to seek the aid of electricity; that opposition—the establishment of competing lines—will prove the powerful factor. Whether it is opposition or not, economy must be the agent which will chiefly operate. Competition, as perhaps may be the case between Manchester and Liverpool ere long, means loss of traffic, and loss of traffic, loss of revenue, and few commercial institutions can prove indifferent to that. Electricity will no doubt effect many changes other than those it is apparently destined to effect in relation to our large railway systems.

Very heartily do I tender most grateful thanks to all those who have taken part in the discussion, or otherwise contributed towards the elucidation of the question dealt with by me. Although I think I may fairly claim to have substantiated the ground assumed in the paper, I welcome such criticism as has been of an adverse character. I feel that it is well that every possible view should be advanced in order that those who may desire to study the question may lose sight of no point which may be material to a fair issue.

The Three Hundred and Fifty-Fourth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, 25, Great George Street, Westminster, on Thursday evening, December 13th, 1900, Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on December 6th were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that they should be suspended.

The following transfers were announced as having been approved by the Council, viz.:—

From the class of Associates to that of Members—

Harold William Couzens.

From the class of Members, Northern Society of Electrical Engineers, to that of Members, Institution of Electrical Engineers—

Llewellyn Andrew.

A donation to the Benevolent Fund was announced as having been received since the last meeting from Mr. Augustus Stroh, to whom a vote of thanks was unanimously accorded.

ON RAPID VARIATIONS IN THE CURRENT THROUGH THE DIRECT-CURRENT ARC.

By W. DUDDELL, Wh. Sc., Associate.

It may be thought by some that the title of this paper is rather contradictory in that there should not be any variation in the current through a direct-current arc. I will therefore explain at once that I simply use the term "direct current" as implying that the current is supplied by cells or by a direct-current dynamo, and not as implying that the current is necessarily constant in value. It may also be as well to state that by *Arc* I do *not* mean *Arc Lamp*, as all the effects to be described are quite apart from those produced by regulating mechanisms.

The effect of varying the current through the direct-current arc very slowly, so slowly in fact that the carbons have time to burn into shape corresponding to each value of the current, has been investigated by many experimenters, but it is to Mrs. Ayrton[1] that the honour belongs of giving a complete investigation of all that occurs when any of the variables in the direct-current arc are changed in any way. The other extreme, namely, very sudden changes in the current, has also been investigated by Mrs. Ayrton,[2] thus leaving a gap in the experimental evidence as to what occurs between very slow variations and isolated sudden changes in the current.

The present paper is an attempt partly to fill this gap by giving an account of what occurs when the current is periodically varied more or less rapidly over a range which is very small compared with the mean value of the direct current.

The current through a direct-current arc supplied with power from any circuit may vary either owing to changes taking place in the circuit, such as variations in E.M.F. or resistance, or owing to effects in the arc itself, such as hissing, humming. Although any variation in the current naturally entails a corresponding change in the arc itself, it will, I think, be found convenient to classify the observed effects according to whether the primary cause of the variation is in the arc or in the circuit which supplies it.

PART I.

CAUSE OF THE VARIATION OF THE CURRENT IN THE CIRCUIT SUPPLYING THE ARC.

The effects of varying the current may be divided under four heads, viz., the effect on the P.D. between the terminals of the arc, on the light emitted, on the shape of the craters, and on the vapour column. These will be considered in order. I shall assume in all cases in Part I. that the amplitude of variation of the current from the mean is small, generally much less than 10 per cent., and that the arc experimented on is neither hissing nor humming.

[1] *The Electrician*, vols. xxxiv., xxxv., and xxxvi.
[2] *The Electrician*, 1895, vol. xxxiv., pp. 471, 541.

Effect on the Potential Difference produced by Variations of the Current.

If the current varies very slowly, then the relation between the P.D. current and length is that given by Mrs. Ayrton's curves. Directly the rate of variation is increased so that the carbons have not time to burn into shape, corresponding with the instantaneous values of the current, the relation will be changed, and it is conceivable that *if* the rate of variation were high enough and the amplitude small enough, the conditions of the arc would in no way be changed, so that the ratio of the change in P.D. to the corresponding change in current, would be a constant and equal to the true resistance of the arc. I shall show later that this assumption, which is the basis of several experiments on the resistance of the arc, notably those by Messrs. Frith and Rodgers,[1] requires a much higher rate of variation of current than they employed.

One of Mrs. Ayrton's curves, contained in a letter by Prof. Ayrton to *The Electrician*,[2] illustrates very well how the connection between the P.D. and current depends on the rate of variation of the latter. This curve shows that the *first* effect of *suddenly increasing the current* through a cored-solid arc [3] is to cause a *transient rise in the P.D.* between the terminals; the effect of a *slow increase of current* being, as is well known, to produce a *decrease in the P.D.* This first transient rise in the P.D. which was obtained with a cored-solid arc, was also, I believe, obtained with a cored arc, but I am unaware of its having been observed for a solid arc.

Thinking that this might be due, as pointed out by Prof. Ayrton, to the extreme quickness of the phenomenon when *both* carbons were solid, I tried to record the transient rise in P.D. for the solid arc by means of an oscillograph, the sudden increase of the current being obtained by discharging a condenser through the arc. This experiment was successful, and a transient rise in P.D. was observed, *the P.D. and current increasing together, but only for about*

[1] *Proceedings of the Physical Society*, 1896, vol. xiv., p. 307.
[2] *The Electrician*, 1896, vol. xxxvii., p. 321.
[3] "Solid," "solid-cored" and "cored" arc mean, respectively, arc between two solid carbons, between one solid and cored, and between two cored carbons; the top or + electrode being always placed first.

$\frac{1}{5000}$ *second*. At the end of this very short time the P.D. decreased with an increase of current in the ordinary way.

If it can be assumed that during this first $\frac{1}{5000}$ second the conditions of the arc are not changed, then the solid arc has a positive resistance, contrary to the results obtained by Messrs. Frith and Rodgers, and it is at any rate evident that, had the frequency of their superimposed alternating current been 5,000 $\sim$ per sec. instead of 250 $\sim$ per sec., the sign of the resistance as obtained by them would have changed, though I do not say that even at that frequency its true value would have been obtained. In any method for measuring the resistance of the solid arc which depends on the change in the P.D. produced by a change of current, these changes must, therefore, take place in less than $\frac{1}{5000}$ sec. in order not to allow the arc conditions to change; results to be described later indicate a still shorter time.

I will not, however, pursue this subject any further, as it would unduly extend the length of this paper to include a description of a complete series of experiments on the resistance of the arc which I have recently completed.

EFFECT ON THE LIGHT EMITTED PRODUCED BY VARIATIONS OF THE CURRENT.

It is well known that the light of the arc varies when the current is changed, though how small and rapid the variation in current may be and yet produce a perceptible change in the light does not seem to have been investigated. Professor Fleming and Mr. Petavel [1] and Mr. Burnie [2] have determined the instantaneous values of the light and current in the case of alternate-current arcs, and have found that the variation in light roughly follows the variation of the current; the maximum luminous intensity occurring about $\frac{1}{1000}$ sec. later than the maximum current. Herr Görges [3] has also noticed that the variations in the current due to the teeth on the armature of a dynamo produced an appreciable variation in the light at the rate of 300 per second.

[1] *Proceedings of the Physical Society*, 1896, vol. xiv., p. 115.
[2] *The Electrician*, 1897, vol. xxxix., p. 849.
[3] *Electrotechnische Zeitschrift*, 1895, vol. xvi., p. 548.

In order to test how rapid and how small a variation of the current from the mean could be detected in the light of the direct-current arc, I arranged an arc so that its image as seen through a central slit parallel to the carbons was projected on to a rapidly falling photographic plate, the instantaneous value of the current being recorded simultaneously on the same plate by means of an oscillograph. The small quick variations of the current through the arc were produced by passing the oscillatory discharge of a condenser in series with a self-induction through it, so that the arc current consisted of a large constant part on which was superimposed a small ripple which died away after a few oscillations.

By this method I find that in an 8-ampere solid arc a *distinct variation is produced in the light emitted by both the + crater and the vapour column when the amplitude of the variation of the current from the mean is only 3 per cent. and the frequency of these superimposed variations is as large as 4,300 ∿ per sec.* At this frequency the variation in light became indistinguishable when the amplitude of the variation of the direct current was reduced to 2 per cent.

Owing to the difficulty in estimating the points of maximum density in the band on the plate which represents the light emitted in consequence of the smallness of the variation of the current and therefore of the light, I was unable to be certain whether the maximum light lags behind the maximum current; but if it does, the lag is very slight, not exceeding $\frac{1}{10000}$ sec. for an 8-ampere solid arc.

It must be remembered that the above variations of light are those of the actinic rays which affect the photographic plate; the visual rays will probably vary in a similar manner, though possibly not to the same extent.

Effect on the Craters produced by Variations of the Current.

Mrs. Ayrton tells me that she noticed that the variations in the current used by Messrs. Frith and Rodgers, who superimposed an alternating current of 0·5 to 1·0 ampere R.M.S. value, at frequency of 100 ∿ per sec. on a 10-ampere direct-current arc, so altered the shape of the ends

of the carbons that she could easily distinguish them from normal carbons formed without any variation in the current. I find that if the superimposed alternating current be reduced to 0·1 ampere under the same conditions, the ends of the carbons appear unaffected.

EFFECT ON THE VAPOUR COLUMN PRODUCED BY VARIATIONS OF THE CURRENT.

SOUNDS.

Corresponding with each value of the current through the arc there is probably a definite cross-section of the vapour column, so that if the current varies rapidly through an arc of fixed length, the volume of the vapour will also vary and sound-waves will be given out. This, I believe, is the generally accepted explanation of the humming of the alternate-current arc.

In the case of the direct-current arc, sounds are also emitted even when the variations in the current are very slight. For example, the variation of current caused by the commutator segments of a direct-current dynamo passing under the brushes can be heard in the arc. This variation of the current caused by the commutator segments, even when in good condition, was found by Messrs. Frith and Rodgers [1] in the case of a 5 k.w. two-pole machine to vary between 2.5 and 9 per cent. of the mean current according to the position of the brushes.

Another striking example of how sensitive the arc is to small variations in the current is furnished by the fact that a Wehnelt interrupter, working an induction coil on the direct-current street mains, will cause any arc supplied by the same mains to give out the same noise as the interrupter itself, even when a considerable distance intervenes between the place where the arc is connected with the mains, and where the interrupter and coil are joined on, as observed by Herr Simon,[2] Mrs. Ayrton, and Mr. Jervis Smith.[3]

It must be clearly understood that the arcs here referred to are normal silent arcs ; that is, if they were supplied with

[1] *Proceedings of the Physical Society*, 1896, vol. xiv., p. 307.
[2] *Annalen der Physik und der Chemie*, 1898, vol. lxiv., p. 233.
[3] *The Electrician*, 1899, vol. xliv., p. 16.

a really steady current they would have been practically silent.[1]

In order to determine what variation in the current was necessary to cause the arc to emit a clearly audible note, the current from a high-frequency alternator, kindly lent by Sir D. Salomons, was superimposed on the direct current by the method shown in Fig. 1. The current from the alternator passes through a condenser F, a dynamometer D, and the arc in series; and it is practically prevented from flowing through the cells which supply the arc by the self-induction L. The direct current is prevented from flowing through the alternator by the condenser F.

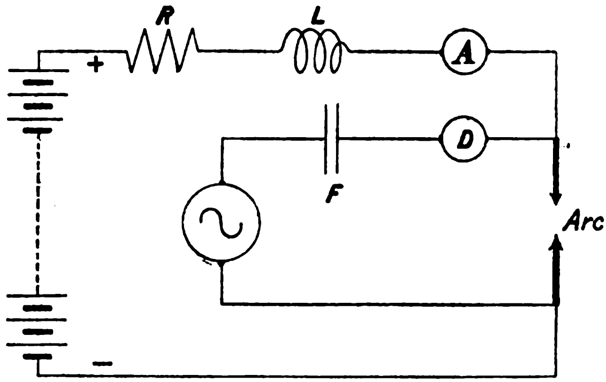

FIG. 1.

It was found by this means that a 10-ampere direct current, solid or cored arc, length 3 to 5 mm., would produce a distinct note even if as small a R.M.S. current as $\frac{1}{1000}$ ampere, as measured by D, was superimposed on the direct current for frequencies of the added current from a few hundred up to 8,000 ∿ per second. Thus *a variation of the order of* 1 *part in* 10,000 *from the mean current will alter the vapour column sufficiently to produce sound-waves.*

Further experiments with another alternator and R.M.S. superimposed currents of $\frac{1}{20}$ to $\frac{1}{10}$ ampere on a 10-ampere solid arc, proved that the sounds only became inaudible at frequencies approaching 30,000 ∿ per second.

[1] Absolute silence is almost impossible, as the least want of homogeneity, or impurity in the electrodes, causes small spits and sounds.

At these frequencies I am uncertain whether the arc had really ceased to give a note, as the ear fails to detect sounds of so high a pitch.

This sensibility of the arc for very small changes in its current explains the fact that not only can rapid variations of current in any circuit supplied from the same generator as the arc be heard in the arc, but also variations of current which occur in a totally independent circuit supplied by a separate generator can be detected in the arc due to mutual induction between the two circuits.

ARC AS A TELEPHONE RECEIVER.

The fact that the arc is sensitive to such small variations

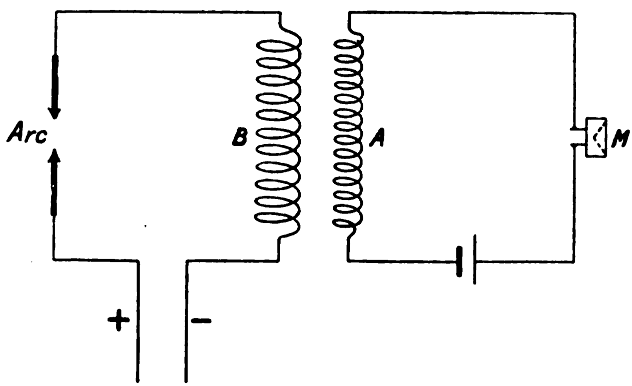

FIG. 2.

in the current and over such a wide range of frequency, at once suggests that the direct-current arc might be used as a telephone receiver. This suggestion, which was made in a leader of *The Electrician* in 1899, had already been carried out by H. Simon [1] in 1898.

The method used by H. Simon for superimposing a microphone current on the main arc current is shown in Fig. 2, in which A and B are two coils having mutual induction, and M the microphone. The current through A varies when M is spoken into and induces E.M.F.'s in B, which vary the current through the arc in such a way that it reproduces sounds and even speech distinctly.

[1] *Annalen der Physik und der Chemie*, 1898, vol. lxiv., p. 233.

The variation of the current through the arc obtained by this method is not as large as it might be, as the E.M.F.'s induced in B have to send currents round the whole arc circuit, including any steadying resistances, and also through the self-induction in the armature, if a dynamo is used, instead of only through the arc where the varying currents are actually required. I have obtained a better result by replacing the alternator of Fig. 1 with a microphone and mutual induction as shown in Fig. 3. A and B are the two coils of a mutual induction, F a condenser of about two or three microfarads, and L a high self-induction, the object of the self-induction being to prevent the microphone currents flowing round the cells instead of through the arc.

With this arrangement and suitable arc conditions, to be explained later, *the arc will speak sufficiently loudly and clearly to be heard at a distance of* 10 *to* 12 *feet in a quiet room.* [Experiment.][1] The sound-waves given out by the arc are, therefore, of such an intensity that when the energy is spread over a spherical surface of 20 feet diameter, the ear placed at any point can hear speech distinctly. It seems probable that if all the energy available could be collected and concentrated on the ear, very powerful sound-sensations might be produced.

The loudness of the sounds given out by the arc is increased by lengthening the arc, as this increases the volume of the vapour column which emits the sounds. It would also seem as if increasing the main current which increases the cross-section of the arc should also be beneficial, but experimentally I have not found

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The microphone M was supplied by the National Telephone Company and intended for long-distance transmission, two accumulators being used in series with it. The mutual induction A : B consisted of a solenoid 30 cms. long wound with about 1,200 turns of No. 18 D.S.C. wire in six sections having an iron wire core about 15 mm. diameter. Diameter of solenoid over winding = 54 mm. For the experiments 3 sections = 600 turns were used for A, and two sections = 400 turns for B.

Resistance of A = 1·52, of B = 1·53 ohms. Mutual induction $25{\cdot}3 \times 10^{-3}$ henrys. Cored carbons were used in the arc, the other data being those given above.

If a suitable mutual induction A : B is not available a self-induction may be used, by connecting the leads from the microphone and cells to the terminals of B instead of those of A, B being now simply a coil having high self-induction and low resistance.

any appreciable gain. The best results have generally been obtained with a current of 10 to 12 amperes, carbons 11 to 13 mm., and an arc length of 20 to 30 mm.

To obtain these long lengths with ease, it is necessary to use cored carbons or some other means of introducing foreign bodies, such as salts of potassium and sodium, into the arc, for there is not much doubt that the stability of the arc between ordinary cored carbons is due to the presence of potassium silicate in the core.[1] (See also Appendix I.) These salts may be introduced either by soaking the carbons in their solutions, or by using them as cores. Mr. Jervis

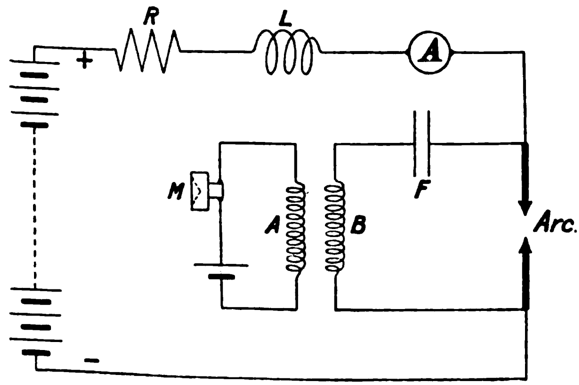

FIG. 3.

Smith has recommended the insulator glass as a core, which I find works well.

ARC AS A TELEPHONE TRANSMITTER.

Before leaving the subject of the use of the arc as a telephone, it will be convenient to consider its use as a telephone *transmitter*, though this subject strictly belongs to Part II. of this paper.

H. Simon found that if he replaced his microphone in Fig. 2 by a telephone receiver, *any sounds made near the arc were heard in the receiver*. In this case, as before, I find

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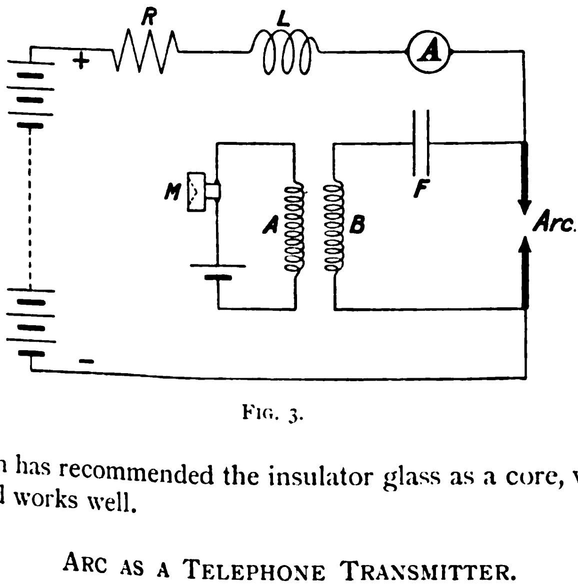

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it preferable to modify his method by connecting the receiver in series with a condenser between the terminals of the arc, as in Fig. 4.

A sound-wave striking the arc may affect it in two ways, either by vibrating the arc as a whole and varying its length, or the waves of condensation and rarefaction may alter the cross-section of the arc: both of these effects will tend to alter the apparent resistance of the arc, and hence vary the current through it.

The sounds obtained in the telephone receiver when using the direct-current arc as a transmitter are not generally very satisfactory, as, besides not being very loud, they are obscured by the extraneous sounds due to the small spits and hisses which occur in the arc each time the air gets to

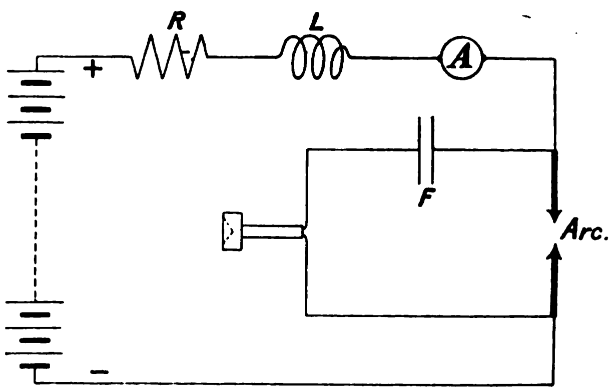

FIG. 4.

the + crater due to any slight defect in the carbons. If a common pair of carbons be used containing cracks and impurities, the noise in the receiver is sometimes unbearable, although there is no outside source of disturbance of the current through the circuit.

In all experiments on the arc as a telephone transmitter or receiver, it is essential that the current generator should be free from rapid variations, or extraneous sounds will be produced. If a dynamo has to be used, then the variations of the current produced by the commutator segments may be minimised by inserting a large self-induction in series with the arc, as in Figs. 1, 3, and 4. This self-induction serves the double purpose of keeping extraneous variations

HUMMING ARC.

CARBONS : + 11 and – 9 mm. Solid "Apostle." Mean P.D. = 50·5 volts. Mean Current = 15·2 amperes.

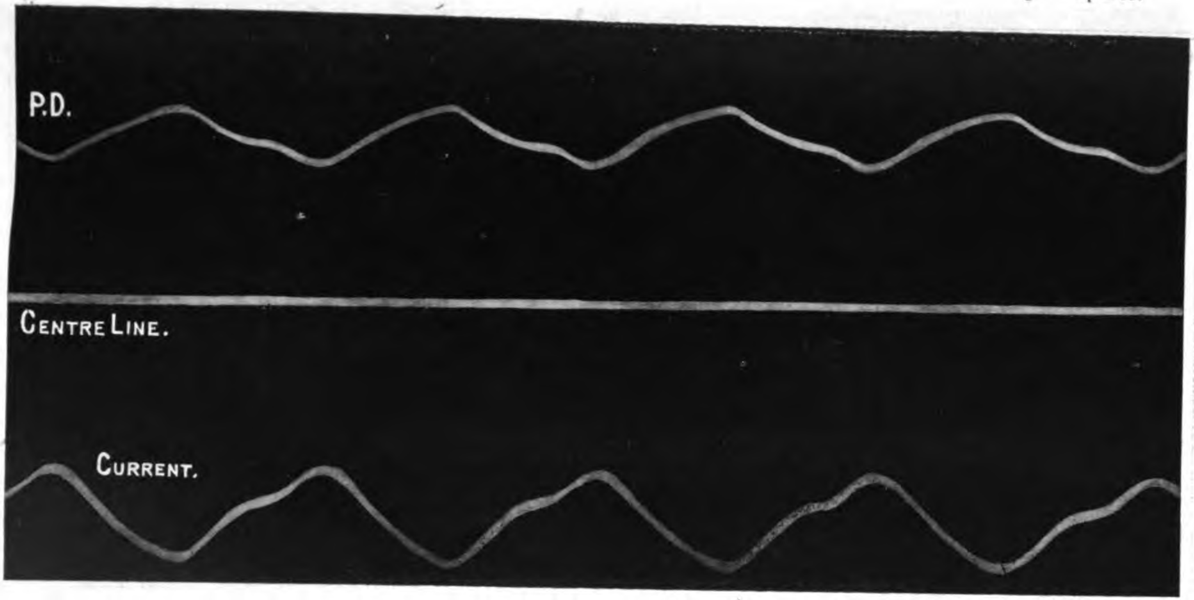

FIG. 5.

Scales :—1 mm. = 0·5 volt = 0·186 ampere = $\frac{1}{6400}$ second. Centre Line = 40 volts = 20 amperes.

HISSING ARC.

CARBONS: + 11 and − 9 mm. Solid "Apostle." Mean P.D. = 38 volts. Mean Current = 22·3 amperes.

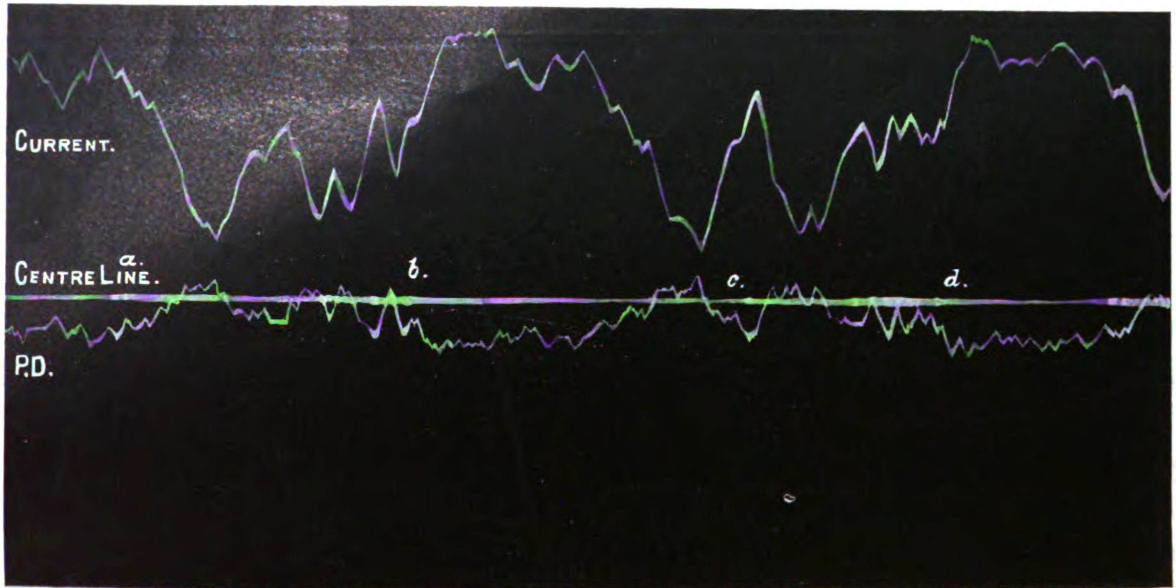

FIG. 6.

Scales:—1 mm. = 0·5 volt = 0·1 ampere = $\frac{1}{5400}$ second. Centre Line = 40 volts = 20 amperes.

HISSING ARC.

CARBONS: + 11 and − 9 mm. Solid "Apostle." Mean P.D. = 45·5 volts. Mean Current = 19·5 amperes.

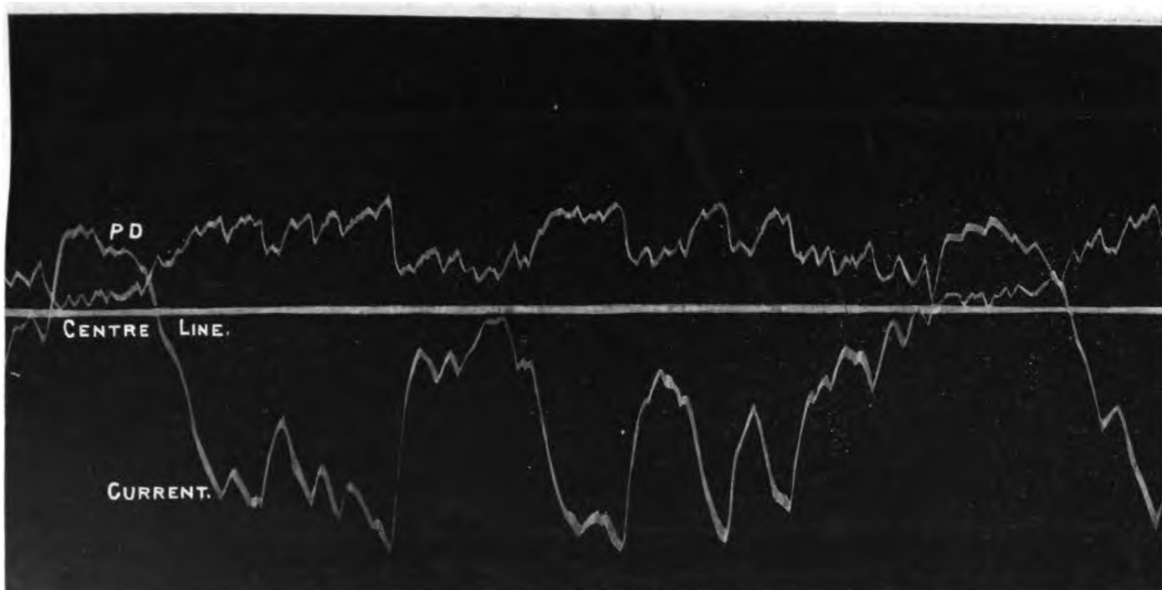

FIG. 7.

Scales:—1 mm. = 0·5 volt = 0·1 ampere = $\frac{1}{6400}$ second. Centre Line = 40 volts = 20 amperes.

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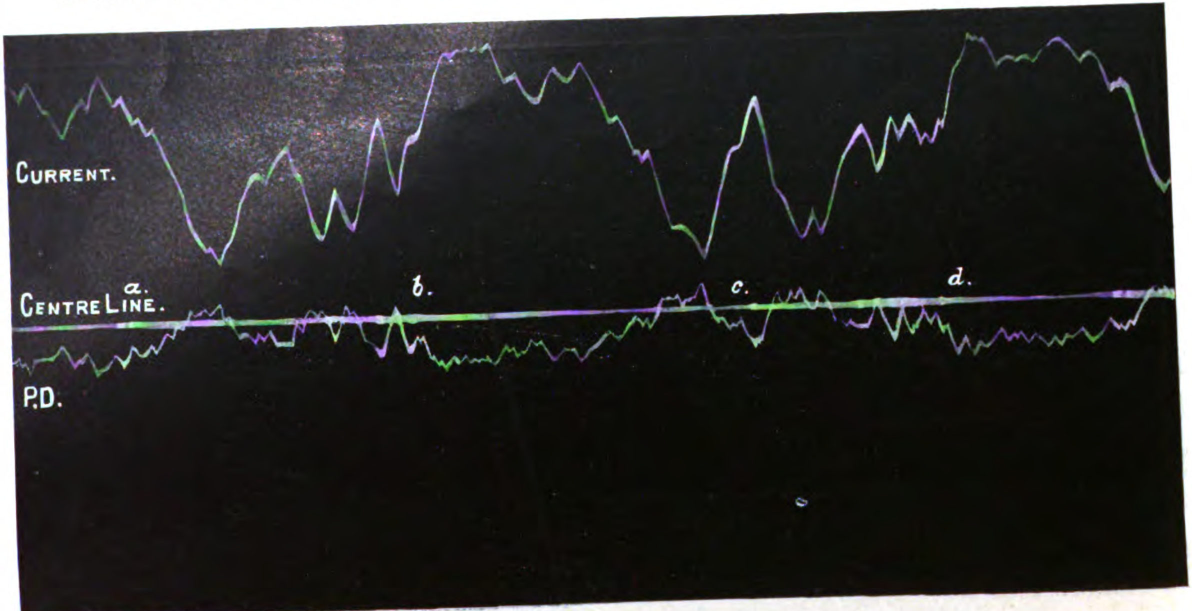

FIG. 6.

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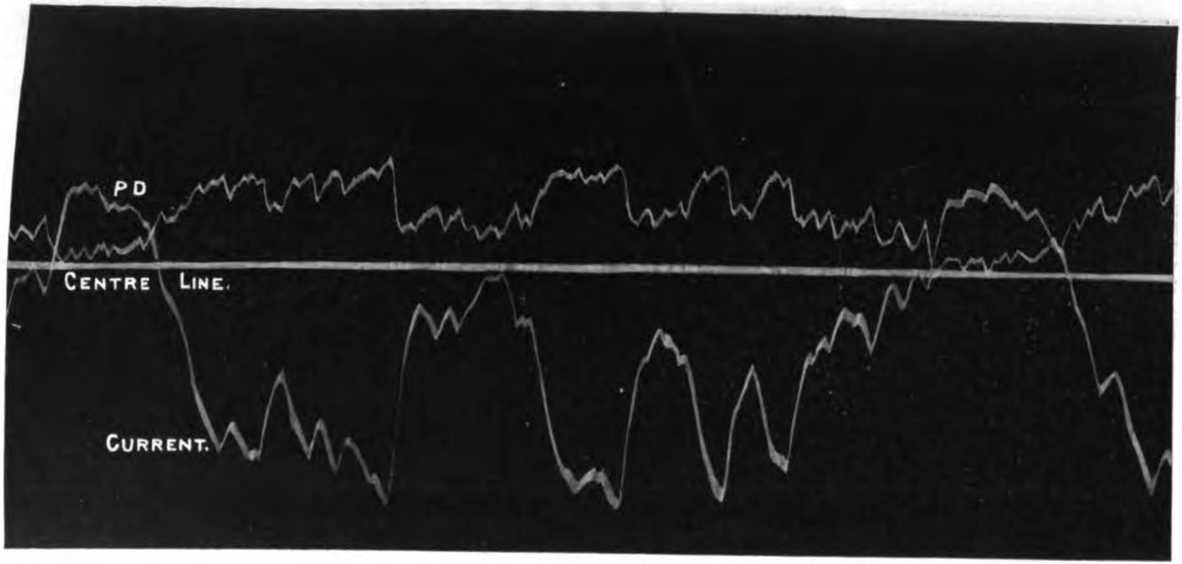

FIG. 7.

Scales:—1 mm. = 0·5 volt = 0·1 ampere = $\frac{1}{6400}$ second. Centre Line = 40 volts = 20 amperes.

VERY SHORT HISSING ARC.

CARBONS: + 11 mm. Cored "Apostle"; − 9 mm. Solid "Apostle."

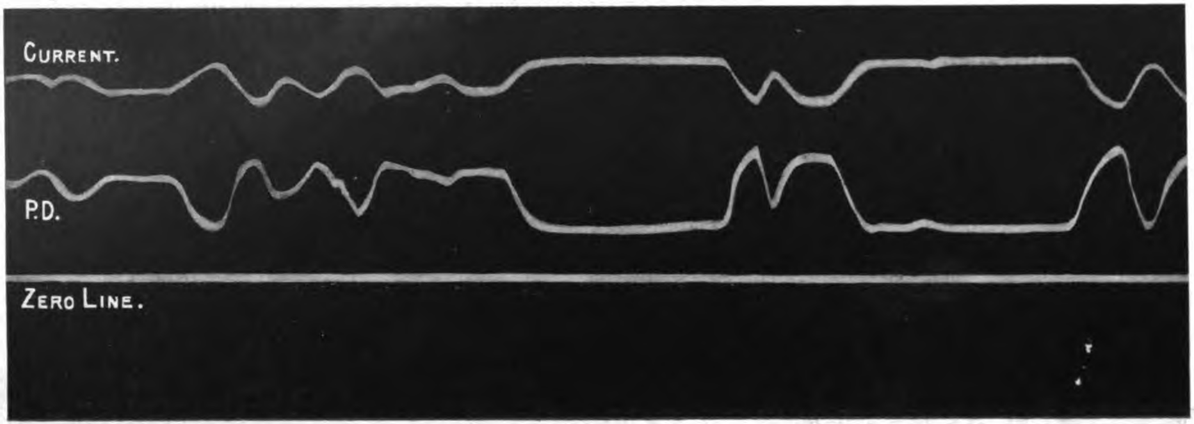

FIG. 8.

Scales:—1 mm. = 1·5 volt = 1·0 ampere = $\frac{1}{8400}$ second.

of the current out of the arc, and of preventing the variations we desire to observe from being dissipated in the source of supply.

Thus we see that *the direct-current arc is not only extremely sensitive to small variations in its current of almost any frequency, but also that it is affected by such small changes of outside conditions as sound-waves produce.* Whether this sensibility can be turned to useful account in telegraphy or telephony remains for future experiment to decide.

PART II.

CURRENT CAUSED TO VARY BY THE ARC.

HUMMING.

Mr. Trotter[1] discovered that the direct-current humming arc rotates, including a coma-like appearance at the + crater, and he also found that the current through the arc varied periodically, the frequency of these variations being the same as the pitch of the humming sound produced, and as the speed of rotation of the arc.

In order further to investigate the connection between the variation of the light P.D. and the current, I have recorded the P.D. and current by means of an oscillograph, the humming arc experimented on being used as the source of light to illuminate the oscillograph mirrors. The arc was so inclined that only the light from the + crater and a small part of the vapour column reached the mirrors. So that the density at any point of the lines represents the photographic intensity of the light emitted at that instant in the direction of the mirrors by the + crater and part of the vapour column, and the distance of the point from this zero line measures the P.D. or the current as the case may be.[2]

A typical example of the variations observed in the humming arc is given in Fig. 5, from which it will be seen that the P.D. current and light emitted in a fixed direction vary in a regular periodic manner with the same frequency.

The variation of the current, which is about 6 per cent.

[1] *The Electrician*, 1894, vol. xxxiii., p. 298.

[2] In Figs. 5, 6, and 7, the centre line is not the zero line, but represents 20 amperes and 40 volts.

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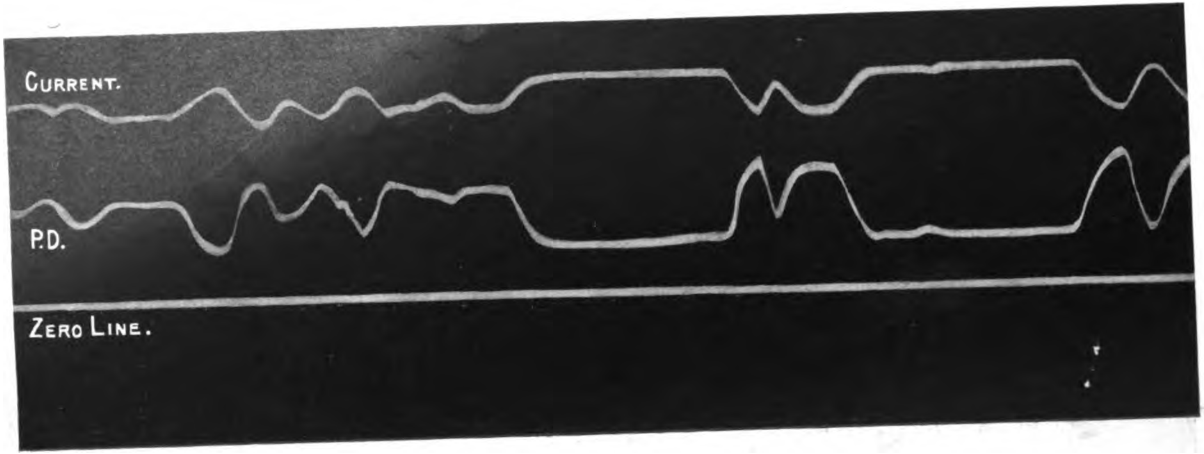

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Thus besides the rotation of the humming arc and the variation of the current observed by Mr. Trotter, I find that the light and P.D. vary with the same frequency, so that in the humming arc the frequencies of the rotation of the arc, and of the variations in the P.D. current, and light emitted in a given direction, are identical with the pitch of the note given out.

Hissing.

It has been shown by Messrs. Frith and Rodgers[1] and by Messrs. Duddell and Marchant,[2] that when a direct-current arc supplied from a constant source hisses, the current through it and the P.D. between its terminals vary rapidly; and M. Blondel[3] and Mr. Brown[4] have also found that the light emitted varies.

If the current through the humming arc be increased until the arc hisses, the variations in P.D., current, and light change, I find, in a most striking manner from the regular periodic variations of Fig. 5 to the very irregular variations shown in Figs. 6 and 7.

In spite of the very irregular nature of the variations, which irregularity is not surprising in view of Mrs. Ayrton's explanation of the cause of hissing given before this Institution last year, I think that they can be separated into two kinds, a large comparatively slow variation, and a rapid superimposed one. The light given out is alternately bright, with rapid variations in intensity, *a* to *b* Fig. 6, and dull with hardly any variations, *b* to *c*; the slow varia-

[1] *Proceedings of the Physical Society*, 1896, vol. xiv., p. 320.
[2] *Journal of the Institution of Electrical Engineers*, 1899, vol. xxviii., p. 86.
[3] *La Lumière Electrique*, 1892, vol. xliii., p. 54.
[4] *Physical Review*, 1898, vol. vii., p 210.

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In view of the explanation given in the case of the humming arc that the large variations of the light is due to its rotation, and in view of the fact that the hissing arc is also probably rotating, as pointed out by Mrs. Ayrton, I think that the larger variations of P.D., current, and light in the hissing arc must also be due to the rotation of the arc. If this is the case, then the brighter parts of the curves are produced by light from the + crater and the rapid variations of density chiefly present in these parts of the lines are due to the rapid variation of this light from the + crater. [Experiment.]

Now these rapid variations in the light correspond with the small rapid changes in the current and the P.D., so that *the rapid variations of P.D. and current correspond with the variations of the light emitted by the + crater, and the large slow variations with the rotation of the arc as a whole.*

Considering one of the larger light maxima, say from *a* to *b*, or *c* to *d*, Fig. 6, during which the oscillograph mirrors receive the light from the + crater without being obstructed by the carbon, it will be seen that in many cases the maximum light and minimum P.D. occur practically at the same instant, whilst the *maximum current occurs later than the light maximum.* This is the opposite to what occurs when the current through the arc is varied by any *change in the circuit,* for in this latter case *the maximum current occurs before the light maximum.*

The periodically recurring sequence of events in the hissing arc is thus probably as follows, putting aside the rotation of the arc as a whole. Owing to the crater becoming too large for the end of the + carbon, the air obtains access to the crater surface as found by Mrs. Ayrton, the oxygen of the air there combines with the carbon, causing a rise of temperature, an increase of brilliancy, a drop in the P.D., followed very slightly later by a rise in the current.

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Sounds Emitted by Very Short Arcs.

A very short hissing arc, so short that practically no light can get out from between the carbons, sometimes produces a shrill whistling sound, accompanied by a small tongue of green flame. The variation of P.D. and current for such an arc are given in Fig. 8, in which the current and P.D. have varied between two limits, viz., 22·5 amperes at 24 volts and 28 amperes at 9·5 volts, the former of which would produce a hissing arc, while the later values of the current and P.D. can only be explained on the assumption that the arc is short-circuited by a bad contact, such as a loose piece of carbon. The whistling sound is probably due to the periodical short-circuiting and relighting of the arc.

Sounds Emitted by Very Long Arcs.

The frying sounds emitted by very long arcs, noticed by Mrs. Ayrton,[1] are probably due to the fact that long arcs are very sensitive as telephone receivers, as mentioned in Part I., so that very slight variations in the current will cause them to give out sounds. In confirmation of this it may be mentioned that a *very long silent* arc can be obtained if the arc is supplied with current from *accumulators* which are *not* in use for *any other* purpose, and if the arc circuit be so arranged that *no* variations of the current can be induced, or produced, in it by causes outside the arc.

If, on the other hand, the direct-current arc be supplied by a dynamo, or if the arc circuit be placed so that there is mutual induction between it and leads carrying a dynamo current, then the long arc will give out a sound corresponding with rate at which the dynamo segments pass the brushes. This explanation was, I believe, first suggested by Professor Ayrton and Mr. Mather.

Intermittent Arcs.

If a direct- or alternate-current arc be blown out by means of a jet of air or CO_2, or by means of a transverse magnetic field, it will, under suitable conditions, relight

[1] *The Electrician*, vol. xxxiv., p. 338.

itself; and if the blowing be continued, the arc will be extinguished and relight itself again and again with great rapidity, giving out a harsh sound. The rapidity of these intermittances may be very great; M. Blondel [1] has found them to be as high as 3,000 to 4,000 per second in the case of the alternate-current arc, and M. Abraham [2] has obtained 100,000 per second in the case of the flame discharge.

It was suggested by Professor Fitzgerald that this intermittance of the arc might be used to produce some high-frequency alternating current which I required. I therefore tried rendering a direct-current carbon arc in series, with a self-induction intermittent by means of a magnet. With this arrangement the rate of intermittance was irregular and not very high, probably owing to the E.M.F. of my source of supply being too low, although E.M.F.'s up to 300 volts were employed.

In order to try and overcome this irregularity, I connected a condenser (about 5 mf.) between the terminals of the arc, when to my surprise I found that the direct-current arc was intermittent even when *not* blown in any apparent way either by a stream of gas or by a magnetic field, and further that no self-induction in series with the arc was necessary.

Here then was a puzzle—a direct-current solid arc burning under ordinary conditions with resistance in series, and supplied with current from accumulators, became intermittent and gave out a musical note on simply shunting the arc with a condenser.

Leads were, of course, employed to connect the condenser as a shunt to the arc, and on twisting these leads together so as to destroy the small amount of self-induction which they possessed, I found that the musical note stopped, to be started again on separating the leads; and on interposing in the condenser circuit a loose coil of wire, the sound was greatly magnified. Hence the true statement of the facts is that given below.[3]

[1] *La Lumière Électrique*, 1893, vol. xliii., p. 54.

[2] *Société Française de Physique*, "Séances," 1899, ii. p. 70.

[3] NOTE (*added February 1st*, 1901).—Since writing the above Professor Elihu Thomson has written to me and to *The Electrician* pointing out that he carried out practically identical experiments as early as 1892, and patented this method for producing Alternating Currents. I regret that I was unaware of these experiments at the time of writing the paper, and so omitted to give Professor Thomson credit for them. Professor Thomson's letter, an editorial note on his patent specification, and a reply from me, appear in *The Electrician* for January 18th, 1901, vol. xlvi., p. 477.

MUSICAL ARC.

A direct-current arc of suitable length and current, between solid carbons, will give out a musical note if it be shunted with a condenser in series with a self-induction, as in Fig. 9, even though the source of supply of the current be perfectly constant and the arc be protected as far as possible from any outside cause of disturbance. [Experiment.]

I find that the musical note is produced by oscillatory currents flowing in the circuit composed of the condenser F, the self-induction L, and the arc, Fig. 9, and its pitch is determined by the periodic time of this circuit—that

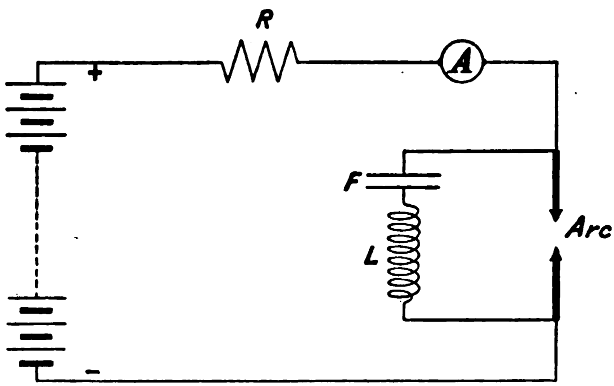


FIG. 9.

is, on the relation between the capacity, self-induction, and effective resistance of the circuit. Neglecting the resistance, which it will be shown later must be small, the periodic time of the circuit $\tau = 2\pi\sqrt{L.F.}$, and this has been found, by judging the pitch of the note by ear, to be approximately correct, so that for lecture purposes Kelvin's law can by this means be easily demonstrated. (See Appendix III.)

It must be remembered that although we have an alternate current through the condenser and self-induction, the source of supply is not an alternating one, and that *it is the arc itself which is acting as a converter and transforming a part of the direct current into alternating, the frequency of which can be varied between very wide limits by altering the self-induction and capacity.* The upper limit I find to be about

10,000 ∿ per second, and the lower limit, if such exists, is well below 500 ∿ per second.

It has long been known that a train of oscillations of almost any frequency can be obtained on discharging a condenser through a suitable inductive resistance, but of course these oscillations have a rapidly decreasing amplitude; and the means of supplying energy to such a circuit so as to maintain *the amplitude of the swings constant*, other than by means of a varying source of power having the same periodic time as the circuit, has been wanting. It is, therefore, necessary to inquire under what conditions it is possible for the arc to cause the source of direct current to supply the energy necessary to maintain the oscillations in the condenser circuit when once they have been started.

If the resistance in the main circuit in series with the arc is large, and if δV be a small instantaneous change in the P.D. between the terminals of the arc, δA the corresponding small change in the current through it, and r the resistance of the condenser circuit, not including the condenser; then, during the time this small change lasts, sufficient energy may be supplied to the condenser circuit to make up for the energy dissipated there, in ohmic losses, if the following conditions are fulfilled (see Appendix II.):—

1. $\frac{\delta V}{\delta A}$, negative.
2. $\frac{\delta V}{\delta A}$, numerically greater than r.

The question is, can the arc fulfil these two conditions? Messrs. Frith and Rodgers [1] have experimentally determined the value of $\frac{\delta V}{\delta A}$, which they call the resistance of the arc, for various arcs, and they found that while $\frac{\delta V}{\delta A}$ was always + when *both* carbons were cored, it was, on the contrary, always − when *both* carbons were solid; and that it was as small as −2 ohms for a 4-ampere solid arc. Now the resistance of the condenser circuit, r, external to the condenser, can easily be made less than 2 ohms, so that the arc can fulfil both the necessary conditions.

[1] *Proceedings of the Physical Society*, 1896, vol. xiv., p. 307.

I will now describe some observations on the musical arc which tend to confirm the above conclusions.

Arcs between solid carbons for which $\frac{\delta V}{\delta A}$ is always negative *work well*, while those between *cored* carbons for which $\frac{\delta V}{\delta A}$ is positive I find *will not work* under any conditions. [Experiment.]

The largest negative value of $\frac{\delta V}{\delta A}$ given by Messrs. Frith and Rodgers is 2 ohms for a 4-ampere solid arc, and it is probable that it did not exceed 2·5 ohms. for the smaller currents, viz., 3 to 3·5 amperes, which I used. According to the above conditions, 2·5 ohms should be the limiting resistance of the condenser circuit; by experiment it was found that when the resistance of this circuit was increased to 2·4 ohms the oscillations stopped and could not be restarted. [Experiment.]

It is evident that besides the resistance there are other causes, such as hysteresis, which tend to dissipate the energy in the condenser circuit and stop the arc giving its note. The hysteresis in an iron-wire core introduced into the self-induction will instantly stop the note. [Experiment.] Any complete circuit such as a ring of wire placed near the self-induction has the same effect. [Experiment.]

On several occasions before the importance of these causes of the dissipation of the energy were realised, considerable trouble was experienced in tracing the reason of the arc failing to give its note. As examples, in one case it was traced to an ammeter and in another to the tinfoil in the condenser which were acting as short-circuited secondaries to the self-induction coil, which had been placed too near them. [Experiment.]

The relation between the self-induction, capacity, and frequency can be very easily demonstrated by playing a tune on the arc by varying either the capacity or the self-induction by means of a key-board. [Experiment.] (See Appendix III.) Another method of varying the self-induction is by separating or bringing closer together the turns of the coil, as if playing on a concertina, the relative positions of the turns determining the self-induction and the pitch of the note. The musical arc can be used as a means of com-

paring self-inductions or capacities by comparing the pitch of the notes produced.

The "enclosed arc" will work equally as well as the open arc, though the note given out is not so audible owing to the globe; but it can easily be made so by taking advantage of some of the telephoning effects mentioned in Part I.

The alternating current through the condenser circuit may be as large as from 3 to 5 amperes R.M.S. value, and the direct current in the main circuit also varies considerably depending on the amount of resistance in the circuit. This condenser current is sufficient to show experiments with alternating currents which do not require much power, and is very convenient in many cases for lecture purposes as the frequency, and any changes in it, are at once evident from the pitch of the note given out by the arc. Magnetic space telegraphy can easily be demonstrated on a small scale by using the self-induction coil as the transmitting circuit. [Experiment.] Several arcs can be used in series when more power is required in the condenser circuit than can be obtained from one arc alone.

TABLE OF DATA OF MUSICAL ARCS.

	Open Arc.	Enclosed Arc.
Carbons both solid.	*Conradty.*	*Electra.*
Diameter	9 mm.	13 mm.
Arc Length	1·5 mm.	1·0 mm.
„ Current	3·5 amps.	5 amps.
Resistance in Series R. ...	42 ohms.	about 28 ohms.
Self Induction of L.	$5{\cdot}3 \times 10^{-3}$ h.	$5{\cdot}3 \times 10^{-3}$ h.
Resistance of L. and Leads ...	0·41 ohms.	0·41 ohms.
Capacity of Condenser F. ...	1·1 to 5·4 mf.	1·1 to 5·4 mf.
R.M.S. Current through Condenser when Capacity = 5·4 mf.	3 amps.	4·5 amps.

For the convenience of those who may wish to repeat these experiments, I have inserted a table of good working

conditions for open and enclosed arcs. The exact figures need not be strictly adhered to, as the musical arc will work over a wide range of conditions. It may perhaps be well to mention that only condensers suitable for high voltages should be used, as although the P.D. arc is only 50 volts, the P.D. condenser rises to several hundred volts.

METAL ELECTRODES SWITCH CONTACTS.

In connection with the above experiments the attempt was made to replace the carbons by metal electrodes, when I found that on trying to shunt the metal arc with a condenser it went out, no self-induction except that of the leads being used. [Experiment.] Of course, whether the arc is extinguished or not depends on the capacity used to shunt it and on the other conditions of the circuit; thus in the present case, with a 3-ampere arc between 6 mm. diameter copper electrodes and a resistance in series of from 50 to 60 ohms, supply voltage 200, it was found that the arc was always extinguished when shunted with a condenser having a capacity from 0·6 to 5·4 mf., though with the smaller condenser, 0·6 mf., and longer arc lengths the extinguishing was not quite so certain. Condensers larger than 5·4 mf. were not tried, though I have no doubt that they would prove even more effective.

This experiment is very instructive as showing how very soon the metal arc becomes practically non-conducting after the current through it is interrupted, for if we consider that the current through the arc is reduced to zero at the instant of first connecting the condenser, and remains zero unless the arc relights, then the time required for the 0·6 mf. condenser to charge up to $(1 - \frac{1}{\epsilon})$, or 63 per cent. of the supply voltage, *i.e.*, 126 volts, is about $\frac{1}{27000}$th of a second. So that we may consider that if the current through the metal arc is interrupted for about one twenty-seven thousandth of a second, even applying about three to four times the normal voltage,[1] will not cause it to relight. This is very different from the case of the arc between cored carbons, for it is well known that the current through a 10-ampere cored arc may

[1] Direct-current metal arcs as above usually require a P.D. roughly about 30 volts.

be interrupted by opening a switch in series with it for, say, a quarter-second, and yet the arc will relight on closing the switch again, owing to the high conductivity of the vapour left, when the arc is extinguished. The comparison is, however, not quite a fair one, as it might be expected that with the larger current, viz., 10 amperes used with the cored arc, more conducting vapour would exist than with the 3 amperes used for the metal arc, and that it would therefore take longer for the vapour column of a 10-ampere arc to cool down and attain a high resistance than that of a 3-ampere arc.

In order to make a fair comparison, the metal electrodes were replaced by cored carbons and a 3-ampere arc obtained under as nearly as possible the same conditions as the copper arc. This cored carbon arc could not be extinguished even on shunting it with the largest condenser, viz., 5·4 mf. [Experiment], and it was found necessary, in order to make the cored arc go out on shunting, to reduce the current through it to below 1 ampere; but with such a small current the arc is rather unstable and liable to go out even when not disturbed in any way. Two solid carbons were also tried, and the effects were found to be intermediate between the cored arc and the metal arc, as a 2-ampere solid arc could just be put out by shunting with the 5·4 mf. condenser, whereas the 3-ampere metal arc always went out on being shunted with a condenser of as small a capacity as 0·6 mf., as already stated.

The correct method of finding out whether the arc will relight in any given case after it has been extinguished on suddenly reducing the current through it, is the following:— Let A, Fig. 10, be a curve which might be drawn between the P.D. which will have to be set up between the electrodes to relight the arc, and the time that has elapsed since the arc was extinguished; and B the curve that connects the actual rise in P.D. between the electrodes (*i.e.*, between the condenser terminals) and the same time. Then the condition for the arc to relight is that the curve B touches or cuts the curve A.

Unfortunately we do not know much about the curve A between P.D. required to relight the arc and time except that it starts from the P.D. at which the arc was burning at the instant it was extinguished, and attains a final constant

value equal to the P.D. required to spark across between the electrodes. We can, however, form some idea of the steepness of the curve A at the commencement, for we know that, if the arc fails to relight, the curve A lies between the ordinate at the time of connecting the condenser and the curve B, that is the ordinate at time nought. The shape of this latter curve, which represents the P.D. between the terminals of the condenser during charge, can be calculated from the known data of the circuit; thus with the copper arc mentioned above, which is just extinguished by shunting

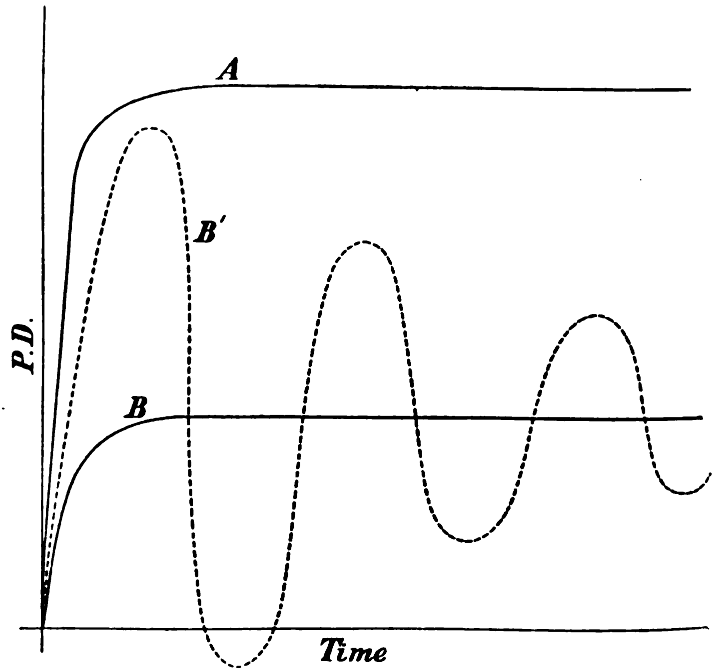
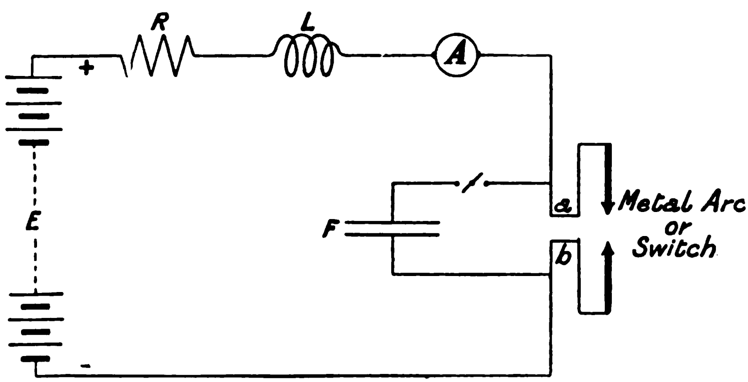


FIG. 10.

with a condenser of 0·6 mf. capacity, E.M.F. in circuit being 200 volts, resistance 56 ohms, and self-induction of leads neglected, the curve B will start with an initial steepness of about 6 × 10^6 volts per second. In spite of this very rapid rise of curve B, it will generally fail to intersect the curve A for the 3-ampere copper arc, so that the apparent resistance of the copper arc seems to increase at a very high rate after the current through it is stopped.

With cored carbon electrodes the arc under similar conditions could not be extinguished by shunting with 5·4 mf., so that since the initial steepness of the curve B was $\frac{1}{9}$th, or about 7×10^5 volts per second, this curve always intersected the curve A for cored carbons. Further, I think that the curves would still intersect, that is the cored arc would relight, if the initial steepness of B had been even many times smaller, so that the rate of increase of apparent resistance of the cored arc after interruption of the current is many times smaller than with the copper arc. In what has been said above, I have neglected the unknown self-



E = 200 volts. *L = 3 henrys (about)*
R = 60 ohms (about). *F = 5·4 microfarad.*
Current = 3 amps.

FIG. 11.

induction of the leads, so that the figures given must be considered as only rough approximations.

The extreme rapidity with which it is necessary to increase the P.D. between the terminals of the metal arc in order that it may relight again after the current through it has been stopped, explains the fact that it seems impossible to maintain an *alternate* current arc between *metal* electrodes at ordinary frequencies and P.D.s of even several hundred volts; and that it requires a P.D as high as 2,000 volts to maintain a metal arc as found by Herr Arons.[1]

If the non-inductive resistance in series with the arc be replaced by a highly inductive one as shown in Fig. 11, the

[1] *Wiedemann's Annalen*, vol. lvii., p. 185.

curve B will be altered in shape, and with the conditions inserted under Fig. 11 the charge of the condenser will be oscillatory as shown by B′ Fig. 10, the maximum P.D. attained if the arc fails to relight at all being many times as high as the E.M.F. of the source of supply. Although the arc is put out on shunting with a condenser, it does not follow that it may not have really relit and gone out again several times corresponding with each swing of the condenser, before it is finally left extinguished owing to the dying away of the oscillations; and this is probably what occurs when the curve A is not very steep, as in the case of cored carbons. In this case the maximum rise in P.D. will be limited by the shape of the curve A and by the amplitude of the oscillations being rapidly damped, due to conduction through the arc.

This high rise in P.D.—caused by the sudden annulling of the current through the self-induction when the metal arc is extinguished on shunting it with a condenser—is very serious, as the following experiment shows. A 3-ampere arc between two copper electrodes 6 mm. diameter, the conditions of the circuit being those given under Fig. 11, was shunted with a condenser 5·4 mf. capacity. This caused the arc to go out and so high a rise in P.D. to be produced that the insulation of the leads broke down, a spark passing from *a* to *b*, accompanied by a report. [Experiment.] When, however, I substituted carbons for the copper electrodes, no report was heard, nor was any serious rise in P.D. noticed. [Experiment.]

The next experiment tried was to connect the condenser permanently as a shunt to the metal electrodes, and then to attempt to strike the arc, the circuit being arranged as in Fig. 11. I found that it was impossible to strike an arc between metal (Cu, Fe, Al, and Brass) electrodes if the capacity of the condenser F, Fig. 11, exceeded 0·1 mf.—even although an E.M.F. of 200 volts was used—and that on separating the electrodes the sudden interruption of the current through the self-induction set up oscillations in the circuit and a high rise in P.D. between the terminals of the condenser similar to that produced when the metal arc was extinguished by shunting with a condenser as explained above. The condition that determines the possibility of striking the arc is similar to the condition that governs the

relighting of the arc after the current through it has been reduced to zero as explained above. For corresponding with each position of the electrodes as they separate there is a certain P.D. required to start the arc, and if the relation between the position of the electrodes and time be known, then a curve between P.D. required to start the arc and time can be plotted similar to curve A, Fig. 10 above, and the intersection or otherwise of this curve with the curve B′ determines whether the arc will strike or not.

The practical interest in this subject of the striking of the arc lies in the fact that when the attempt is made to interrupt a steady direct current flowing through an inductive circuit by means of a switch with metal contacts, an attempt is really made, at the first instant, to strike a metal arc between the contacts, and if these contacts be shunted by a condenser which prevents the arc from forming, a high rise in P.D. will occur. If, however, the arc was allowed to form, the time during which the break takes place would be lengthened, and no such great rise of P.D. would be produced. This rise in P.D. has been mathematically investigated by Mr. Johnson [1] on the assumption that the arc does not form, and putting the data given under Fig. 11 into his equation, I find that the rise in P.D. is just over 2,000 volts as compared with 200 volts the E.M.F. in the circuit. It is, therefore, of importance when it is required to prevent these rises in P.D., on breaking the circuit to so choose the substance of the switch contacts that the arc shall not be prevented from forming or be suddenly extinguished by the action of the condenser, that is to say *that arcing at the switch contacts should rather be encouraged than otherwise*, of course always supposing that no special method such as a non-inductive resistance shunting the switch be provided to dissipate the energy stored in the self-induction.

The following experiments illustrate the importance of the nature of the switch contacts and of the condenser which shunts them. The circuit used was that shown in Fig. 11, the arc being replaced by a switch with brass contacts, and the data of the circuit being those given below the figure. When the condenser F was disconnected, and the insulation between *a* and *b* was made to consist of a single thickness of paper, I found that the circuit might be

[1] *The Electrician*, 1900, vol. xlv., p. 281.

made and broken by means of the switch, either quickly or slowly, without the paper between *a* and *b* being pierced. [Experiment.] After reconnecting the condenser F, however, every time the switch was opened the paper was pierced, and even three thicknesses of the paper could not withstand the rise in P.D. that occurred. [Experiment.] The steady P.D. required to pierce one thickness of the paper was found by a separate experiment to be about 550 volts, and that required to pierce three thicknesses about 1,500 volts, so that without the condenser shunting the switch the rise in P.D. on breaking the inductive circuit was under 500 volts, but with the condenser as a shunt to the switch was over 1,500 volts, showing that the metal arc must have been almost completely suppressed, as the maximum value of the P.D. calculated above on the assumption of no arc forming at all was only just over 2,000 volts.

The influence of the nature of the contacts of the switch on the rise in P.D. which occurs when the switch is shunted by a condenser is very marked; thus with the metals, copper and brass, serious rises in P.D. were always found to occur, with solid carbons as contacts the rise was much less, and with cored carbon contacts was inappreciable. [Experiment.]

Breaking the circuit between metal contacts under tap-water, or shunting the metal contacts while in air by wires dipping into water, also prevented any serious rise in P.D.

It was also found that resistance or self-induction introduced into the connections between the condenser and the contacts greatly reduced the rise in P.D. on opening the switch.

I attempted to use an electrostatic voltmeter to measure the rise in P.D. instead of the rough method of the piercing of paper, but although the voltmeter was sufficiently sensitive to read steady P.D.s much below that required to pierce the paper, it failed to indicate the rises in P.D. This is probably due to the short time the rise in P.D. lasts.

There are two practical cases in which capacity shunts the switch contacts to which I will refer.

The first is the ordinary induction coil in which the circuit is the same as Fig. 11, the switch being replaced by the contact maker. In this case a high rise in P.D. is

required so that the nature of the contact points should be such that the arc can be completely extinguished by as small a condenser as possible ; for the rise in P.D., if the arc is completely extinguished, will be the higher the smaller the capacity of the condenser. (See also Appendix IV.) It is evident, therefore, that carbon would be very unsuitable for the contacts of an induction coil. This has lately been shown to be the case by the experiments of Mr. Beattie,[1] who finds that with a slow break the maximum length of spark obtainable between the terminals of the secondary, using *platinum contacts*, is nearly 2½ times that obtainable when *carbon contacts* are used, the current interrupted at the break being the same in both cases. I think that if *cored carbons* had been used, a much greater disparity in the spark length would have been found. [Experiment.]

The second case is that of a switch or circuit breaker connected with a concentric cable so that the capacity shunting the contacts is supplied by the distributed capacity of the cable. Whether this distributed capacity in practical cases will have the same effect as a condenser shunting the contacts, as suggested by Mr. Johnson, is, I think, a matter for further experiment. If it has, then serious rises in P.D. are to be apprehended on interrupting a *direct* current, though an inductive circuit, by means of metal contacts, the capacity of the cable forming a shunt to the contacts.

Assuming this to be true for *direct* currents, may not some of the breakdowns of concentric cables supplying power by means of *alternating* current be also due to the sudden quenching of the arc at metal contacts, and not to the fact that the current is an alternating one ? I suppose, of course, that the attempt to interrupt the current is made at some point in the period when the current is large.

Before concluding this paper, I wish to express my indebtedness to Professor Ayrton and Mr. Mather, of the Central Technical College, not only for allowing me to carry out the experiments in the laboratories of the College, but also for the valuable assistance and advice they have given me during the course of the experiments. I also wish to express my thanks to the many students who have helped me from time to time, and especially to Messrs. Brown, Watson, and Fithian.

[1] *Phil. Mag.*, 1900, vol. L, p. 146.

Conclusions.

If the current be suddenly increased through a direct-current arc between two solid carbons, the P.D. and current increase together for less than about $\frac{1}{5000}$ second, and at the end of this very short time the P.D. decreases with an increase of current in the ordinary way.

If the current through a direct-current arc varies by as little as 3 per cent. from the mean, and if the frequency of these superimposed variations is even as high as 4,300 ∿ per second, a variation in the light emitted by both the + crater and the vapour column can be detected.

A rapid periodic variation of the order of one part in 10,000 from the mean current will alter the vapour column of the arc sufficiently to produce sound-waves; and a variation of one part in 100 will produce sound-waves even at frequencies as high as 30,000 ∿ per second.

The arc is affected by such small changes of outside conditions as sound-waves produce.

The direct-current arc can be used both as a telephone receiver and transmitter.

In the direct-current humming arc the P.D. current and light emitted vary periodically, the frequency of these variations being the same as that of the rotation of the arc as a whole, and of the pitch of the sound emitted.

In the direct-current hissing arc the P.D. current and light emitted vary very irregularly, the larger and slower variations corresponding with a rotation of the arc as a whole and the smaller and more rapid to the hissing proper, *i.e.*, the oxygen of the air obtaining access to the crater surface as demonstrated by Mrs. Ayrton.

Under certain conditions the direct-current solid arc will emit a musical note when shunted by a self-induction in series with a condenser.

When emitting the musical note, the direct-current arc transforms direct-current energy into alternate-current energy, the frequency of the latter being determined by the self-induction, capacity, and effective resistance of the oscillating circuit. The pitch of the note emitted may be used as a means of comparing self-inductions and capacities.

If a direct-current arc be shunted with a condenser of several microfarads capacity, the arc will generally be ex-

tinguished if the electrodes are of metal, and not if they are of cored carbon, the resistance in series with the arc being non-inductive.

If the resistance in series with the arc be highly inductive, then, when the metal arc is extinguished by shunting it with a condenser, a violent rise in P.D. occurs between the terminals of the arc.

The rise in P.D. that occurs when an inductive circuit is broken by means of a switch, the contacts of which are shunted by a condenser, is much higher if their contacts are of metal than if they are of cored carbons, owing to the condenser extinguishing the metal arc formed at the contacts more suddenly than the arc formed when carbon contacts are separated.

APPENDIX I.

On the Resistance of the Cores of Cored Carbons.

I do not remember having seen it pointed out that the much greater stability of arcs between cored carbons than of those between solid carbons can not be very well due to the high conductivity of the material of the core, while in place in the carbon, for the cores have generally a higher specific resistance than the solid carbon which surrounds them, as the following experiment shows :—

Three carbons were taken—two cored and one solid—of the same nominal diameter (11 mm.), and a current of 9·9 amperes was passed through them. The drop of volts was measured along a length of 20 cms. of each after they had attained a steady temperature.

Each of the three carbons then had a hole 3·16 mm. diameter drilled through it so as to completely remove the cores of the cored carbons and the centre of the solid carbon, and the drop of volts was remeasured as before. The results are given in the table below, from which it appears that drilling a hole in the solid carbon increased its resistance 7·8 per cent., whereas drilling the same sized hole (which removed the core and a small amount of the solid carbon) in a cored carbon of the same make only increased its resistance by 2·1 per cent.

Allowing for the fact that a small quantity of solid carbon was removed along with the core in drilling, *the specific resistance of the core, of one make of cored carbon, was about sixteen times that of the surrounding solid carbon, and in the other the specific resistance of the core was practically infinite.*

Make of Carbons	"Apostle" *Solid.*	"Apostle" *Cored.*	"Brush" *Cored.*
	mm.	mm.	mm.
Mean diameter	10·97	10·95	10·70
Mean diameter of core	—	2·84	2·82
Drop of volts along 20 cms. *before* drilling ...	1·71	1·74	1·52
Drop of volts along 20 cms. *after* drilling ...	1·84	1·77	1·56
Per cent. increase of resistance due to drilling..	7·8	2·1	2·4
Ratio $\frac{\text{Specific resistance of core}}{\text{Specific resistance of surrounding solid carbon}}$	about	∞	16

APPENDIX II.

On the Conditions which Govern the Conversion of Direct Current into Alternating Current in the Musical Arc.

(See Fig. 9.)

Let E and C be the E.M.F. and current through the cells, when there is no oscillatory current through the condenser circuit.

Let V and A be the P.D. and current through the arc under the same conditions.

Let R be the resistance in series with the arc, including that of the cells.

Let r be the resistance of the condenser circuit.

Let δV be a small change in the P.D. arc which produces a current δi through the condenser circuit for a time δt, and let δV and consequently δi be assumed to change sign at the end of each interval of time δt.

Let δA and δC be the corresponding changes in A and C; E being assumed constant.

The energy supplied to the condenser circuit—

during one interval $\delta t = (V + \delta V)(+\delta i)\,\delta t$

" next " $\delta t = (V - \delta V)(-\delta i)\,\delta t$

Total during one complete period $2\,\delta t = 2\,\delta i\;\delta V\,\delta t$

Energy dissipated in ohmic losses during $2\,\delta t = r(\delta i)^2\,2\,\delta t$

In order that, during each complete period $2\,\delta t$, energy may be supplied to the condenser circuit, we must have

$$\delta i\;\delta V \text{ positive.}$$

And in order that this supply shall make up for the ohmic losses we must have

$$\delta i\;\delta V \geq r(\delta i)^2$$

Now

$$\delta C = \delta A + \delta i$$

$$\text{and } C = \frac{E - V}{R}$$

$$\therefore \delta C = \frac{-\delta V}{R}$$

$$\text{and } \delta i = -\frac{\delta V}{R} - \delta A = -\left(\frac{1}{R} + \frac{\delta A}{\delta V}\right)\delta V$$

$$\delta i\ \delta V = -\left(\frac{1}{R} + \frac{\delta A}{\delta V}\right)\left(\delta V\right)^2$$

$\therefore$ for a supply of energy to condenser circuit $\frac{\delta V}{\delta A}$ must be negative and numerically less than R.

Supposing $\frac{\delta V}{\delta A}$ negative, then in practice the second condition is always fulfilled, or $\frac{\delta V}{\delta A} + R$ would be negative and the whole circuit unstable.

Next the condition that sufficient energy be supplied to make up for the ohmic losses gives

$$\delta i\ \delta V \geqslant r(\delta i)^2$$

and as $\delta i\ \delta V$ is positive,

$$r\frac{\delta i}{\delta V} \leqslant 1$$

$$-r\left(\frac{1}{R} + \frac{\delta A}{\delta V}\right) \leqslant 1$$

$\therefore$ to obtain best supply of energy to condenser circuit we require R very large and r very small.

Suppose $\frac{1}{R}$ may be neglected, compared with $\frac{\delta A}{\delta V}$ then condition becomes

$$-\frac{\delta V}{\delta A} \geqslant r$$

Thus it is possible if $\frac{\delta V}{\delta A}$ is negative and numerically greater than r, for the condenser circuit to receive sufficient energy during each very small complete oscillation to compensate for the energy dissipated in ohmic losses during the oscillation. For larger oscillations, similar but more complicated expressions will probably be required.

APPENDIX III

On the Relation between the Pitch of the Note and the Capacity and Self-Induction Shunting the Musical Arc

In order to demonstrate that the pitch of the note emitted by the musical arc is determined by the capacity and self-induction of the

circuit shunting it, and is given by the formula frequency of note emitted $= \frac{1}{2\pi\sqrt{LF}}$, when the resistance of the circuit is negligible, a series of capacities was calculated by means of this formula, to give one octave of the diatonic scale, on the assumption of a constant self-induction L. A fairly close approximation to this series of capacities was obtained by combining in parallel condensers chosen from a set of eight Swinburne condensers, the capacities of which are given below. A keyboard was constructed which made the necessary connections. The condensers used in parallel and their actual capacities are tabulated against the notes on the keyboard they were respectively intended to produce. This arrangement of condensers and keyboard, arrived at entirely by calculation, was that used to play tunes on at the meeting.

The self-induction L consisted of a coil of about 40 lbs. of No. 10 D.C.C. copper wire coiled into a coil of about 18 inches diameter, having a resistance of about 0·44 ohm and a self-induction of 14·75 henrys.

The frequency of each of the notes emitted by the arc was determined for me by Mr. G. Wall and Mr. L. Murphy by comparing, by means of a monochord, each note with a standard tuning-fork giving 512 complete vibrations per second. The frequencies so determined are tabulated below along with the frequencies calculated by means of the formula from the known self-induction and the capacity in each case. The agreement between the two demonstrates, I think, fairly conclusively that the pitch of the note is determined by the periodic time of the circuit shunting the arc. It will be noticed that the calculated frequency is in most cases about 1 per cent. higher than the observed; this is probably due to the fact that in calculating the frequencies no account has been taken of the resistance of the circuit in which the oscillating currents are flowing, as this resistance should include that of the arc. This is borne out by the fact that the note depends to a slight extent on the length of the arc and on the current through it. Another possible cause of the difference may be that the capacities of the condensers used may not be quite the same at these high frequencies, 550 to 1,100 $\sim$ per second, as at 100 $\sim$ per second, the frequency at which they were determined.

LIST OF SWINBURNE CONDENSERS.

Called.	Capacity in Mfs.	Called.	Capacity in Mfs.
a	2·515	*e*	0·307
b	1·142	*f*	0·119
c	1·146	*g*	0·130
d	0·612	*h*	0·057

DATA OF CONDENSERS FOR MUSICAL ARC.

Note on Keyboard.	Condensers Used in Parallel.	Capacity in Mfs.	Frequency ∿ per Second.	
			Calculated.	Observed.
C	*a, b, c, d, g*	$5 \cdot 54_5$	558	545
D	*a, b, d, g*	$4 \cdot 39_9$	624	618
E	*a, d, e, f*	$3 \cdot 55_3$	695	688
F	*a, d*	$3 \cdot 12_7$	740	735
G	*b, c, g, h*	$2 \cdot 47_5$	832	822
A	*b, d, f, g*	$2 \cdot 00_3$	926	915
B	*b, e, g*	$1 \cdot 57_9$	1042	1045
C	*b, f, g*	$1 \cdot 39_1$	1110	1101

To increase the alternating current in the condenser circuit and the loudness of the notes emitted, it is necessary to increase the number of

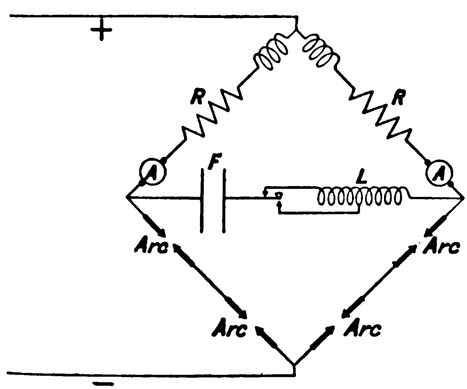


FIG. 12.

solid arcs used in series. With the ordinary 200-volt supply only three solid arcs can be run in series, and even this number gives trouble owing to want of sufficient stability. In order to overcome this difficulty I employed the arrangement shown in Fig. 12, by means of which all the advantages in stability of having only two arcs in series are secured at the same time that, as far as the condenser circuit is concerned, we have four arcs in series and the consequent increase in the alternating current and the loudness of the notes emitted. As used at the meeting the data were as follows: Pressure of supply 200-

volts current through each arc 5 amperes. Carbons + 11 and − 9 mm. solid "Apostle." Arc length about 1 mm. F condenser and keyboard described above. L self-induction described above, with an extra point brought out so as to reduce its value to ¼ and give a second octave.

APPENDIX IV.

(*Communicated February 22, 1901.*)

During the experiments on the shunting of a metal arc with a condenser, I noticed that the rise in P.D. which occurs between the terminals of the arc when the circuit is inductive always seemed to be greater when the condenser was applied as a shunt to an arc after striking the same than when the electrodes were first shunted with a condenser and afterwards the attempt was made to strike the arc. Prof. Fitzgerald suggested to me, quite independent of the above observation, that in the case of an ordinary induction coil an increase of spark length might be obtained if instead of connecting the condenser, as is usual, permanently as a shunt to the contact points the condenser was disconnected during the time the contact points separate to a small distance, and was then connected as a shunt to them so as to suddenly extinguish the small arc or spark that had formed between them.

In order to carry out this suggestion a contact maker driven by a motor was constructed by means of which the condenser could be connected as a shunt to the contacts, which acted as the interrupter for the primary current of the induction coil either before their separation (ordinary method) or at any desired time interval after the separation of the contacts and the formation of the arc between them (new method).

With this apparatus, using a six-inch spark "Apps" induction coil the primary current being supplied by three accumulators and regulated by means of a carbon resistance, and using the condenser belonging to the coil, I found that if the primary current was adjusted to give the maximum length of secondary spark, first with the condenser applied before the separation of the contacts, second with the condenser applied a certain time after their separation, then the spark length in the latter case (new method) was from two-and-a-half to three times as great as in the former or ordinary way. Again, if, when the spark length was adjusted to its maximum value with the new method, the condenser was applied in the ordinary way without changing the current or the speed of the contact maker, then the secondary spark was reduced to about one-sixth or one-seventh the length, so that the new method of applying the condenser to the induction coil gives in both cases a considerable increase of spark length over the old.

An observation was made whilst working with this contact maker on the curious way in which a trace of oil on the contacts affects the secondary spark length. If, with the condenser connected in the ordinary way, the current through the contacts was so small that

practically no arc formed between them, then a trace of paraffin oil on the contacts *increased* the secondary spark length. If, on the other hand, the current was so large that appreciable arcing was taking place, then the oil on the contacts *reduced* the spark length, apparently due to the oil being decomposed, and introducing carbon vapour into the arc between the contact points, thus reducing the suddenness of the interruption of the primary current.

The PRESIDENT: It is quite evident we have not time for much discussion, and I am sorry to say the discussion on this paper cannot be adjourned. I think, however, we ought to call upon Professor Ayrton to say how it bears upon that negative resistance of his which was so much maligned some time ago. The President.

Professor W. E. AYRTON: The paper which we have just heard read has given me exquisite pleasure: not because I have any claim to be its author, although I felt as pleased while I heard it read as if I had been the writer; nor is it merely because I feel convinced that these experiments of to-night will assist in the development of the electrical industry of to-morrow: it is rather because it so rejoices the hearts alike of professional men—yea, and of professors—to find a student who so resembles a solid carbon arc that he is ever on the alert to catch at and magnify any hint which may come from Nature or man. From Mr. Duddell's papers of two years ago, and of to-night, we learn much; among other things this second one has taught us how valuable was that research made some five years ago by Messrs. Frith and Rodgers. For what did that investigation really show us? It brought out an absolutely new fact. Supposing this is an alternating-current circuit (Fig. A), the alternator running at a given frequency and supplied with a given exciting current, the alternating current in the circuit being measured by an accurately graduated alternate-current ammeter, and that this is a wholly separate circuit—a direct-current circuit supplied by accumulators—and sending a direct current through a solid carbon arc. Then what they showed was this, that if you make a break in this alternate circuit and insert the solid carbon arc (Fig. B) without making any change in the resistance, speed, or excitation of the alternator, etc., you increase the alternate current, not merely the current when flowing in one direction—for the condenser stops any direct current—but you increase the current in *both* directions; that is, the alternate-current ammeter reads higher after the arc has been inserted than it did before, and higher than it will if the arc be short-circuited. Now that investigation was undertaken by these gentlemen because certain theoretical considerations led me to suggest that if the method that had been employed by various experimenters to measure the resistance of the arc—a method employed without comment or adverse criticism as long as a positive answer was obtained—was applied in a certain case to an arc a negative answer for the resistance of the arc would be found: that the method, in fact, which up to that period had been used successfully to give the resistance of the arc, and which had always given a positive value, I pointed out would give under certain conditions, a negative answer. Certain preliminary experiments Professor Ayrton.

Professor Ayrton.

having been made by Mr. Mather which confirmed my idea, a long investigation was carried out by Messrs. Frith and Rodgers. And they found that whenever the arc was formed between *solid* carbons, the ratio of an instantaneous change of P.D. to the corresponding instantaneous change of current was *negative*, whereas if the carbons were *both cored* it was always *positive*.

A howl of indignant criticism followed. Had Messrs. Frith and Rodgers and I lived in the Middle Ages we should undoubtedly have been burned in the solid carbon arc. But there were three distinguished investigators who had the insight, who had the courage, not to be drawn into this net of conventional antagonism, and these were Professor

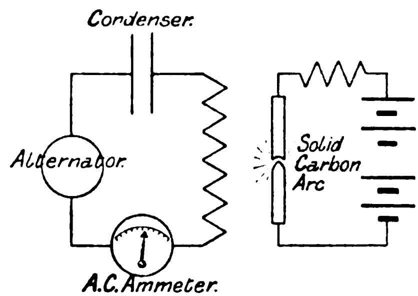


FIG. A.

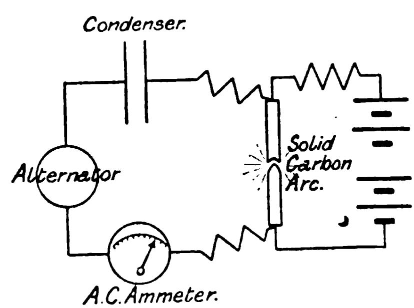


FIG. B.

Gray, then of Bangor, now Lord Kelvin's successor at Glasgow, Mr. Oliver Heaviside, and last but by no means least, the Chairman of your Dublin local section, Professor Fitzgerald, to whom we, like so many experimenters, are indebted for the many suggestions which he has made. And I, even I, ventured to suggest that progress would be more expedited, I thought, if the critics, instead of merely cavilling at the anatomy of the sugar figure on the cake, would cut it open, and see whether there were really any plums inside. It has remained, however, for Mr. Duddell to be the real Jack Horner to put in his thumb and pull out the plum, and modestly leave you and me to finish the rhyme and add "what a good boy he is."

Professor Ayrton.

I do not propose this evening to consider whether or not what Messrs. Frith and Rodgers measured was the true resistance of the arc, because opportunity, I hope, we shall soon have of going fully into the subject; but in justice to Messrs. Frith and Rodgers, and in virtue of the far-reaching principle that they really brought to light, I desire to emphasise what they really obtained. Mr. Duddell has taught us what was the real significance of their work. Our lost friend Professor Hopkinson, following Mr. Wilde, proved several years ago that two alternators could not be run in series. Thus, for example, if an alternator with a certain exciting current supplied to it, and driven with a steam engine, or an electric motor, or whatever it might be, were coupled mechanically to another similar alternator, driven by an independent steam engine, and speed were got up so that the two machines were going exactly in step and then were joined in series with some outside circuit, he proved to us that the moment this mechanical coupling was severed the two alternators would get out of step. So, as is well known, two alternators cannot run in series. And he might have added—if there had been the slightest necessity for him to do so—that if two alternators cannot continue running in series even if they have been started with the same frequency and exactly in step, still more impossible must it be for one alternator, driven by its own steam engine, to run in series with another independently driven when the frequency of the second is being altered within wide limits. Nevertheless, gentlemen, that is exactly what the arc does. For in Fig. B we have one alternator running in series, with a second alternator, viz., the solid carbon arc, supplying alternating current to the circuit—because the arc transforms direct-current energy into alternate-current energy—and does it in such a way that whether the frequency of this alternator be as Messrs. Frith and Rodgers found, seven periods per second, or 70, or 170, or 250, which was the highest limit which could be obtained in my laboratory at that time, and whatever the current might be, within the limits they tried, this gallant little alternator—the solid carbon arc—helps the other, and supplies current sufficiently in phase as to make the alternate current greater when it, the arc, is inserted than when it is taken away or short-circuited.

Mr. Duddell has not only pointed out the importance of that result, the novelty of that result, but he has pointed out something even further. He has shown us that an ordinary so-called perfectly silent arc supplied with current from accumulators is, if the carbons be solid, like the mouthpiece of a flageolet or flute, not blown. The application of a shunt to that arc, consisting of a capacity in series with a self-induction, performs two operations. It starts vibrations in the arc, just as blowing a flute gives rise to vibrations of many different rates. Just as one of those rates of vibration is picked out and reinforced in the case of a flute or flageolet by the form of the resonance chamber dependent on the position of your fingers or keys, so in this musical arc the particular one of the many vibrations that is probably started which is picked out and reinforced depends on the capacity of the condenser and the value of the self-induction which is in series with it.

Professor Ayrton.

Already he has shown you a practical result that has followed from this. I do not mean merely those illustrations which he has given of magnetic space telegraphy, and by means of which he has shown how it has become possible to easily and experimentally demonstrate that the E.M.F. of the current induced in the distant secondary coil is proportional to the frequency of the alternating current in the primary, which will be of marked value to teachers; but beyond that he has shown us how to much improve a well-known instrument. The other day he demonstrated in my laboratory that, adding to the ordinary circuit of that very induction-coil, joined up as usual, his little motor so as to put the condenser across the break *just after* the break was made, a spark was obtained from five to seven times as long as was obtained with the coil in the ordinary way. Even if you try to make the comparison absolutely fair, and try to arrange the very best conditions in each case for the old method and for the new method, you still find a great advantage. Let somebody take, for example, an induction coil and arrange the battery-circuit, contact-breaker, etc., in the old way as well as he can, and let Mr. Duddell use the same induction-coil, battery, condenser, etc., and deal with it as well as he can, then the spark produced in the latter case will be from 2½ to 3 times as long as in the former.

There is one other point which has come out in connection with these experiments of a rather different kind. Some ten or more years ago a paper was read by Dr. Sumpner and myself before the Royal Society, pointing out what was then new, that in the case of an alternating-current arc, if we used solid carbons, the true power given to the arc, that is the power measured by some accurate method, was considerably less in some cases than the current measured by a good current ammeter multiplied by the pressure measured by an alternate-current voltmeter. Subsequently to that, in making experiments I was pretty convinced that under certain circumstances a direct-current arc behaved in the same way. I was pretty certain, in the case of a direct-current arc, especially when solid carbons were used and the arc was hissing, that the power-factor was no longer unity, but not sufficiently sure of the fact to publish it, especially in view of the way in which that other paper which I have just referred to was received at the Royal Society, and the scepticism which was raised when Dr. Sumpner and I pointed out how far from unity we found the power-factor was with certain alternate-current arcs. But now I am sure, from results of experiments which have been recently made in my laboratory, that with an arc supplied with accumulators, a so-called steady direct-current arc, if the carbons be solid and there is hissing, the power-factor may be several per cent. different from unity—that is, the true power as measured by a true instrument, for example a good wattmeter, may be several per cent. less than the product of the voltmeter reading into the ammeter reading.

When I read this paper of Mr. Duddell's, I thought he had proved that a solid carbon direct-current arc was the most sympathetic soul I had ever met, but you have convinced us that that is not quite the case, for you have shown Mr. Duddell this evening that the sympathy of his arc is even exceeded by the sympathy of his audience.

Dr. Fleming.

Dr. J. A. Fleming: It is very difficult to decide who ought to be congratulated the more heartily this evening; the members of this Institution for having had an opportunity of hearing such a delightful paper from Mr. Duddell, or Mr. Duddell himself for having completed such an excellent piece of scientific work. It is a paper which I am sure must especially gladden the heart of our President, for if I mistake not it will have important practical results in connection with electrical engineering, and it will perhaps assist in showing that science sometimes does go before practice, and not follow it.

The matter that has most interested me has been the experiments with the continuous-current arc setting up oscillations in a circuit containing a condenser short-circuited on the arc, because I have been attempting something in that direction lately, only unfortunately I have concentrated all my attention on the alternating-current arc between metallic electrodes, whereas I ought to have directed attention to carbon electrodes. I am afraid it will be a matter of regret to me that I made that choice. It is, of course, a well-known fact that if an alternate-current arc between metallic balls is used, strong oscillations can be set up in a condenser circuit shunting the balls, especially if the arc is blown upon by a well-regulated current of air. But the effect with the continuous-current arc is exceedingly interesting, because it seems to depend on certain critical conditions as to the state of affairs when the arc is extinguished. If I mistake not, a rough explanation of it is something in this direction. Imagine the condenser and inductive circuit to be placed across the carbons when the arc is in operation. Then at that moment the arc is robbed of its current, and is extinguished. Then the potential rises, the condenser becomes charged, and it discharges itself through what remains of the conducting vapour, and then re-establishes the arc, and so sets up a periodic state of affairs —a sort of flutter is created in the arc which expresses itself in a musical note. But, as Mr. Duddell points out, it will not take place if cored carbons are used, and it will not take place if metallic electrodes are used. It seems to be perfectly clear from his experiments that the reason why it will not take place with a metallic electrode is because the arc vanishes too quickly. Perhaps the reason why it will not take place with the cored carbons is that the conducting vapour remains too long. In that case I should like to know whether the sound will be produced by cored carbons if blown upon by a gentle current of air.

Certainly one of the most practically important parts of Mr. Duddell's paper is the final section, in which he deals with the question of switch contacts, and, if I mistake not, that will cause some heart-searching to those who have been responsible for the manufacture of high-tension switches. Hitherto the idea has been in the minds of every one of us that what a high-tension switch ought to do is to have jaws which fly apart as quickly as possible, and break the arc as rapidly as possible. That, according to these experiments, is exactly what it ought not to do. I lately came across, in a technical journal, an elaborate description of a switch for high-tension purposes. It was to be made of non-arcing metals. I suppose Mr. Duddell will tell us that that is exactly how not to do it, and that what we want to do in constructing a switch of that

Dr. Fleming. kind is not to destroy the arc, but to encourage the arc, only it must be an arc which is under perfect control, and which you can whittle away by degrees, having it under perfect control until it is finally extinguished.

I recollect trying many experiments with carbon poles underneath the surface of water drawn apart in the endeavour to combat some of those very difficulties which Mr. Duddell alludes to at the end of his paper, when he speaks about the risks and dangers of interrupting alternating currents in concentric cables. I suppose there is no question that some of those effects have been due to the very things he has explained to us to-night.

There is one other point I should like to notice, viz., experiments with the induction coil. It is well known to every one who handles induction coils that although a coil will work well with a certain number of cells, taking, we will suppose, five amperes and working with ten volts, yet if you try to work that coil upon a 100-volt circuit, and put in a resistance to keep the current down to five amperes, it will not work at all. You get a very reduced secondary spark out of it. And the explanation is clear. When you have the higher voltage, as the contact points separate the arc is drawn out, and the decay of the magnetism of the core is therefore hindered, which is exactly what you do not want. Therefore the moral of these things is, that in the contact of an induction coil you must do exactly the opposite to that which ought to be done when constructing high-tension switches. I am sure all this portion of Mr. Duddell's paper will have valuable consequences in directing those responsible for the design of large switches to consider their ways and be wise.

Mr. Trotter. Mr. A. P. TROTTER (*communicated*): The fact that I have published so little about my researches on the rotatory phenomena of the direct-current arc, makes me reluctant to criticise those parts of Mr. Duddell's paper which cover the same ground, and if I did differ with him on a few isolated points, I do so without diminishing my esteem for the paper as it appears in print, and my admiration for the experiments with which it was so brilliantly illustrated.

The sensitiveness of the arc to small variations of the current was brought to my attention by the clicks which corresponded to the commutator sections of a little motor which I used to drive my stroboscopic discs. The motor was in shunt to part of an iron-wire resistance in series with the arc. I used about 20 amperes on a 100-volt circuit. The motor took about one ampere; I substituted an induction coil for the motor, and the hum or squeak of the contact maker was clearly reproduced by the arc. In both of these cases the main current was not interrupted, but a small change was made in a shunt. I used to work late at night, and did not attempt serious work until I knew by the sound that the Kensington Court dynamos had shut down, and that the supply was derived from the batteries.

I do not think that the model exhibited to show the rotation of the arc gave a good idea of the actual conditions. The crater is horizontal, with a good arc between vertical carbons. With a silent, fairly short arc the cupped surface appears to be uniformly luminous, but on gradually

increasing the current, and before the hum begins, photometrical examination shows the rotatory phenomenon. The bright spot is the "head" of the comma-like patch of luminosity. This spins round, but always within the crater, and it can never be "on the other side of the + carbon" as Mr. Duddell suggests, unless the arc be very long, and the + carbon rounded instead of being flat or cupped, and the arc very irregular. I think Mr. Duddell has rather exaggerated the extent of the rotation, perhaps by way of making the point more clear. But I agree with him generally that the periodic variation of the light is most probably due to the fact that any one portion of the crater supplies at one time a brilliant and at another time a less brilliant light to the oscillograph mirrors. Unless the whole of the light can be collected and dealt with, I do not think that the author is justified in saying that "the light" varies with the frequency of the hum. It is not unlikely, however, that the total light *does* vary; but this, on account of the variation of current rather than on the strength of the author's photographs. Mr. Trotter.

In 1894 I observed the variation of the current by means of a telephone wound with thick wire carrying the whole current of 20 amperes. I made some attempt to measure the variation, as an alternating current, but I had not the means for doing so: this was one of the matters which I wished to investigate before publishing anything more. Other matters which I have regarded as indispensable features of an account of the humming arc are a set of photographs of the "white spot," the "comma," and the "butterfly," and an investigation of the relation between periodicity, of hum, current, and length of arc. The variation of current has been admirably measured by Mr. Duddell, but he has not, I think, thrown any light on the cause of the variation. We merely have his statement, that with a humming arc the current and the volts and the light vary with the frequency of the hum. I see no likelihood of being able to continue my research at present, and I should be glad to see Mr. Duddell or some equally competent investigator take it up where I left off. I think that I can account for the rotation, but I am quite unable to understand the variation of the current.

After a long study of enlarged images of silent, humming, and hissing arcs, the author's diagrams, Figs. 6 and 7, do not convince me that Mrs. Ayrton is justified in suggesting that "the hissing arc is also probably rotating." Examination of the images of hissing arcs with various kinds of stroboscopic discs has not disclosed either rotation or periodicity. The diagrams show exactly what might be expected from a phonograph reproduction of a hiss. The image of the crater of a hissing arc shows a patch or patches of brilliant luminosity jumping about: I can find no better expression. They may flicker with more or less regularity for a second or two, but with an ordinary hissing arc the behaviour is erratic and capricious. Fig. 6 shows three waves having a periodicity of about one hundredth of a second; if this were continued for an appreciable period it would give a hum, sounding the lower G of the bass clef, and in so far as any periodicity exists, the arc is a humming arc as well as a hissing arc. As in the case of the humming arc, the record of the oscillograph cannot be accepted as

Mr. Trotter. indicating the variation of the whole light unless the whole light is dealt with.

Of the remainder of the paper I will say nothing but to repeat my admiration, and of the parts to which I have referred I would say, without disparagement, that they serve to fill up chinks between the classical paper on the Hissing Arc and one on the Humming Arc, which has not yet been written. He who has time and opportunities for writing the latter has some fascinating work to do.

Mr. O'Gorman. Mr. M. O'GORMAN (*communicated*): Mr. Duddell, with admirable self-restraint, puts the suggestion of damage to concentric cables from the sudden interruption of an arc between metal contacts in the shape of a question. His suggestion is very probably right in certain cases, but I think these cases are at present rare, for several reasons.

1. The capacity needed to extinguish suddenly a metallic arc when the voltage was 200 was shown by his experiments to be considerable —as cable capacities go. (The entire eleven miles of the Ferranti Deptford main has only a capacity of 3·8 microfarads, and Mr. Duddell used 5 mfd.).

2. That capacity must be, so to speak, immediately available, not separated from the arc to which it is a shunt by either self-inductions or a resistance, one or both of which are almost always present in the armature of the dynamo, motor, &c., if not in the mains, through which the cable capacity acts on the arc of a switch.

3. The capacity is almost invariably shunted in low-tension systems by the non-inductive filaments of the lights which are not extinguished at the time of the operation of the switch under consideration, for the load on a central station of any magnitude such as would have a large capacity on its mains never falls to zero.

4. The leakage from main to main is almost invariably sufficient to allow a normal current of a few amperes to flow; thus the capacity shunting the arc is itself shunted by a small resistance, say 100 ohms, even supposing the arc to be struck when there are no non-inductive filaments connected.

5. It was proved by Northrup and Pierce (*Electrical World*, Nov. 6, 1897), in a paper quoted by Steinmetz, that the disruptive effect of high-frequency oscillations from a condenser and self-induction, or the peaky volt surgings from an induction coil, is much less than that of a sinusoid alternating voltage, on heavy insulating oils (which are the basis of the bulk of modern concentric cables). Hence 2,000 volts does not of itself always mean a very heavy puncturing effect applied to a cable, though it may mean a great deal with a piece of dry paper, the path across which is practically an air-gap.

On high-tension mains in ordinary practice we are far from getting the short snappy, almost explosive extinction of the spark which Mr. Duddell got on each occasion signalised by the paper puncturing, and I have been unable to speak to any one who has seen such a sudden interruption of the arc in practice on the mains. This is due to two facts. First, that a D.P. switch is always used which disconnects the condenser from the circuit while breaking it; and secondly, if one limb of the switch operates before the other has begun to arc, as is frequent,

or if a single-pole switch is used, the condenser is not directly in shunt across the metal arc between the contacts, but is across them, *in series with the self-inductions of the line and some part of the load in parallel with the alternator.* Whether alternating generators having small self-induction are for this reason to be preferred, is a question which is probably settled by the fact that all alternators now made have such resistance and self-induction that sparks are not usually swamped with this dangerous suddenness. Mr. O'Gorman.

Every one who heard Mr. Duddell's paper must agree that he may justly feel proud of his brilliant success, both in research work and in demonstration.

Dr. E. W. MARCHANT (*communicated*): There is a question which is of some interest in connection with one of the experiments Mr. Duddell showed at the demonstration on December 13th. I refer to that in which the music of the arc was first changed in note, then stopped altogether by the introduction of an iron-wire core into the self-induction he was using. Dr. Marchant.

Apart altogether from phenomena produced by energy absorption, the increased self-induction of the coil produces an increased impedance of the circuit, and a consequently decreased alternating current in the circuit, the impressed P.D. remaining constant. This reduced current gives rise to a diminished expansion and contraction of the vapour column, and consequently a note of less intensity is heard. At the same time, the absorption of energy in the core prevents the amplitude of the oscillations in the circuit increasing beyond a certain limit; they are damped out too quickly. I wish to draw attention more particularly to the causes of the energy absorption. Mr. Duddell describes the effect as being due to hysteresis, but I think he should describe it as an effect partly due to hysteresis and partly to eddy current loss. It does not seem to be generally recognised that the eddy current loss in iron is always very much greater than in any other metal, copper for instance. In several instances descriptions of effects produced by iron wires that are not produced by copper wires have been published, and the cause of the difference in behaviour of the two metals at once put down to hysteresis without taking account of eddy currents, quite forgetful, apparently, of the fact that eddy-current loss in iron wires at ordinary induction densities, is many thousands of times greater than in copper, in spite of the relatively great conductivity of copper. For example with No. 28 soft iron wires, with an induction density of about 15,000 lines per sq. cm. and a frequency of 1,000, the eddy-current loss is double that which is due to hysteresis. It would seem, therefore, in this experiment that eddy currents are at least as potent as hysteresis.

The very interesting experiment shown by Mr. Duddell with an induction coil, in which the spark length from the secondary was increased by connecting the condenser the instant after the spark was formed at the contact breaker, is capable, I think, of a comparatively simple explanation. The experiments preceding this proved that the P.D. induced between metal electrodes is higher when the condenser is suddenly switched on with the arc burning, than when the

Dr. Marchant. current is suddenly switched on, the condenser being always in connection.

When a condenser is switched on between the terminals of a spark-gap, oscillations are set up in the condenser circuit (the frequency of the oscillations depending on the conditions of the circuit) which may enable the arc to restrike. If, however, the time at which the condenser is switched on be so regulated that the arc will just not restrike, the current through the coil is annulled with great suddenness, at a rate calculable from the conditions of the circuit. If, on the other hand, the condenser be applied from the beginning of the break, the arc will be able to restrike, and rapidly alternating currents will traverse the metal arc until the distance between the contact points has so far increased as to prevent this. In other words, the cause of the phenomenon is the fact that the rate of flow of current into a condenser, and the consequent rate of extinction of the current through the induction coil, has its maximum value when the condenser is first connected, a fact known from the solution of the equations determining the charge of a condenser.

I can only add my congratulations to Mr. Duddell on his admirable paper, and still more admirable experiments.

Mr. Russell. Mr. ALEXANDER RUSSELL (*communicated*): For his wonderful discovery of a simple method of obtaining alternating currents of high frequency from the direct-current mains, Mr. Duddell deserves the grateful thanks of all electricians. In case any of those who did not hear Mr. Duddell may think that the method requires elaborate apparatus or careful tuning, the following account of a rough experiment with an ordinary direct-current arc lamp may prove instructive. The lamp was run direct from the hundred-volt street mains through a resistance, and had the ordinary shunt and series regulating coils. A coil of 110 yards of 7/15 cable about 2 feet in diameter, wrapped up as it came from the makers, was put in series with a condenser, and the two were placed as a shunt between the carbons. The condenser was a very roughly made one of about 1·9 microfarad capacity, and was similar to those used with ordinary induction coils. On switching on the current, which was about twelve amperes, a high musical note could be heard very occasionally, but on reducing the current the note became continuous. Placing another coil of cable in the neighbourhood of the first coil, it was easy to feel and easy to see by the sparking on breaking the circuit that powerful induction effects were taking place between the two coils. The induced E.M.F. could also be read on a hot-wire voltmeter up to a distance of two or three feet between the coils.

A Siemens' electro-dynamometer placed in the main circuit read 3 amperes (C), and another in the condenser circuit read 2·1 amperes (I). The resistance of the coil of cable and of the dynamometer and leads was about 0·25 ohms (R), and the musical note given out by the arc showed that the frequency of the alternating current was about two or three thousand per second. The P.D. between the carbons was 48 volts, and the current in the main circuit did not appreciably alter when the condenser circuit was switched on and off.

The power-factors of the arc and the condenser circuit can be easily found. Let $V + e$ be the P.D. between the carbons where V is a constant and e varies, then, as is well known, the effective P.D. will be $\sqrt{V^2 + v^2}$, where v is the effective value of e. Let also R be the resistance of the condenser circuit, shunting the arc when the condenser is short-circited, and let I be the effective value of the instantaneous current in this circuit, then the power expended in it will be $R I^2 + H$, where H represents the power expended in the condenser and in neighbouring metallic circuits. When we can neglect H, the power-factor of the condenser circuit — Mr. Russell.

$$= \frac{\text{true watts}}{\text{apparent watts}}$$

$$= \frac{R I^2}{\sqrt{V^2 + v^2}\, I}$$

$$= \frac{R I}{\sqrt{V^2 + v^2}}$$

$$= 0{\cdot}011.$$

[On switching off the condenser circuit the P.D. fell from 48 to 40. Hence $\sqrt{V^2 + v^2} = 48$, $V = 40$

$$\therefore v = 27$$

In practice v and I do not remain steady for more than a few seconds at a time, and vary between wide limits.]

If C be the current in the main circuit, then the alternating component in C is very small, and so we can consider C as constant.

$$\left.\begin{array}{l}\text{The instantaneous power}\\ \text{expended in the arc}\end{array}\right\} \begin{array}{l} = (V + v)(C - i)\\ = V C - v i + v C - V i.\end{array}$$

Now the mean value of the last two terms for a complete period is zero, and the mean value of $-v i$ is $-R I^2$.

$$\therefore \text{Power expended in arc} = V C - R I^2$$

$$\therefore \text{Power-factor of the arc} = \frac{V C - R I^2}{\sqrt{V^2 + v^2}\sqrt{I^2 + C^2}}$$

$$= 0{\cdot}68.$$

The current through the arc is of course $\sqrt{I^2 + C^2}$, *i.e.*, 3·66 amperes. The power-factor of both arc and condenser circuit taken together

$$= \frac{V C - R I^2 + R I^2}{C \sqrt{V^2 + v^2}}$$

$$= \frac{V}{\sqrt{V^2 + v^2}}.$$

Hence, as Professor Ayrton pointed out, we have part of a direct-current circuit with a power-factor less than unity. The determination

Mr. Russell. of v is not very easy when v is small, as V and $\sqrt{V^2 + v^2}$ are nearly equal to one another. For example, if V is 48 and v is 6, then the difference between V and $\sqrt{V^2 + v^2}$ is only 0·37 of a volt.

Mr. Duddell mentions that for a very rapid rise of i, v shows an initial rapid rise, and hence v and i will have the same sign. This seems to indicate that when the frequency of the natural vibration of the condenser circuit is greater than 10,000 it may be impossible for its current to absorb sufficient energy from the arc to keep up the vibrations, and hence the phenomenon would cease. As Mr. Duddell has not yet published his experiments on the resistance of the electric arc, it perhaps would be hardly fair to ask him to elucidate more fully some of the results in connection with it he has mentioned. So far as interest and importance are concerned, the paper by Messrs. Duddell and Marchant on alternate current arcs was hard to beat, but I think Mr. Duddell has done it.

Mr. Clinton. Mr. W. C. CLINTON (*communicated*): The extinction of the metal arc when shunted by a condenser is probably materially assisted by the superior conductivity of metal electrodes. In confirmation of this it may be noted that extinction under given conditions is certain with copper poles, less certain with zinc, and does not take place with carbon. It would be interesting to know whether extinction is accomplished with the same certainty using copper after the arc had been running for, say, an hour, and everything was thoroughly hot.

Mr. Duddell. Mr. W. DUDDELL (in reply) [*communicated February* 22, 1901]: To the interesting remarks made by Professor Ayrton on the connection between my experiments and those of Messrs. Frith and Rodgers, and on the bearing of these experiments on the value of the resistance of the arc, I will make no reply, as I hope at an early date to enter very fully into this subject.

The fact that the power factor of a direct current hissing arc is less than unity is evident from Figs. 6 and 7, and its value could be calculated from them. Mr. Alexander Russell justly points out that the power factor of the Musical Arc is also less than unity; in fact, if an arc, or any other conductor which has a resistance or an E.M.F. depending on the strength of the current, forms part of a circuit through which a varying current flows, so that the instantaneous values of the P.D. and current do not have a constant ratio, then the power factor of that circuit will be less than unity.

Dr. Fleming, in his explanation of the phenomena of the Musical Arc, assumes that the arc is extinguished at each oscillation; but this is not necessarily the case, as by changing the conditions of the arc, the current can be caused, either to vary over a very limited range without at any instant becoming very small, or it may be caused to vary over such a large range that actual reversal of the direction of the current through the arc takes place, the arc current becoming practically an unsymmetrical alternating current.

Dr. Fleming also asks whether cored carbons can be used if the arc be blown upon by a gentle current of air. Intermittent arcs can certainly be obtained between cored carbons by this means; in fact, so far as I have tried, *intermittent* arcs can be produced between any elec-

trodes with suitable circuit conditions and blowing either by means of a magnet or a current of air. This latter phenomenon, where the arc is, so to say, mechanically extinguished and relights, must not be confounded with the Musical Arc, which depends for its action on a certain specific property of the arc considered simply as an electrical conductor, no actual extinctions or intermittances of the arc being necessary for the phenomena to maintain themselves continuously. Mr. Duddell.

Dr. Marchant raises the question of the connection between the value of the alternating current in the condenser circuit shunting the arc, and the frequency. I have measured this current, and I find it very little affected by change in frequency; this is probably due to the fact that the periodic time of the current is always the same as the periodic time of the circuit, so that it is the resistance of the shunt circuit which determines the flow of the current and not its self-induction or capacity. Dr. Marchant says that "eddy current loss in iron is many thousand times greater, at ordinary induction densities, than in copper," but is this a fact? If the *induction* is the same, then the loss in copper, other things being equal, is greater than in iron. Does not Dr. Marchant mean for the same *magnetising force?* Taking the case of the experiment shown at the meeting of an iron wire core introduced into the self-induction coil stopping the note. The coil used consisted of 98 turns of No. 12 D.C.C. wire, mean diameter 35 cms. Self-induction without core $5{\cdot}3 \times 10^{-3}$ henry. The core used consisted of a bundle 3 cms. diameter of No. 26 iron wires 54 cms. long. Weight 1·9 kilogrammes. The frequency was about 950 $\sim$ per second without the core and was reduced by its introduction, the arc just failing to emit its note when the core was central in the coil. It is improbable that the induction in the core attained 1,000 lines per cm.^{2} so that although the eddy current loss is considerable, I still think that the cessation of the note was mainly due to hysterises, though whether it was due to hysterises or eddy current losses does not affect the object of the experiment, viz., to show that causes which tend to dissipate the energy in the condenser circuit may stop the arc giving its note.

Mr. Clinton asks whether the extinction of the metal arc when shunted by a condenser will take place with the same certainty after the arc has been running for, say, an hour.

I have no experience of metal arcs which have been running for such a long time; after a few minutes the arc is burning between globules of molten metal, and in this condition the extinction still takes place. Any further burning will not, I think, materially affect the conditions, as the molten metal then drops off as it is formed. I am of the opinion that the suddenness does depend on the quickness with which the vapour condenses under the given conditions; thus, if the whole space in which the arc was burning was at a higher temperature than the temperature of volatilisation of the metal, I should expect that extinction would not be produced.

In connection with the subject of the dangers of capacity shunting the switch contacts in inductive circuits, Mr. O'Gorman advances several reasons for thinking that at present such dangers are rare. I am not, however, inclined to agree with him, and if I were re-writing

Mr. Duddell. my paper at the present time, I should no longer use such self-restraint as to put the suggestion of damage to concentric cables in the form of a question. I will consider the reasons he gives as far as possible in order.

1. There are in use at the present time, and their number is rapidly increasing, a considerable number of concentric cables having two or more microfarads capacity, and these capacities would be sufficient to produce the sudden extinction of the arc between the switch contacts under my conditions. It must also not be forgotten that the smaller the capacity, other things being equal, the higher will be the rise of P.D. between the terminals of the switch, supposing the arc is extinguished.

2 and 3. Mr. O'Gorman is quite correct that the capacity must directly shunt the switch contacts and not be separated from them by any considerable self-induction or resistance. This actually occurs in

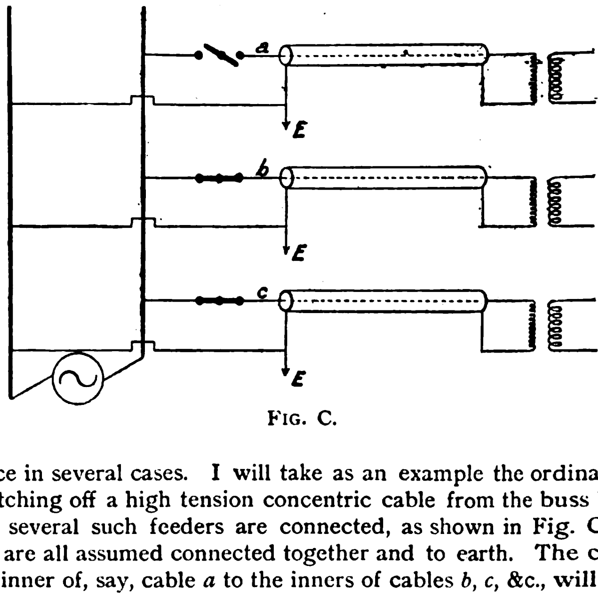


FIG. C.

practice in several cases. I will take as an example the ordinary case of switching off a high tension concentric cable from the buss bars, to which several such feeders are connected, as shown in Fig. C. The outers are all assumed connected together and to earth. The capacity of the inner of, say, cable *a* to the inners of cables *b*, *c*, &c., will be due to the capacity of *a* in series with the joint capacities of *b*, *c*, &c., and will have a value which will range between one half, in the case of two identical cables, and equal, in the case of a large number of cables, the capacity of the inner to the outer of each cable. This capacity of the inner of *a* to the inners of *b*, *c*, &c., *directly shunts the contacts of the switch* in the inner of *a*, so that if an inductive load be connected to the cable, we have all the necessary conditions for a serious rise in P.D. between the switch contacts and consequent danger to the *cables.*

In spite of Mr. O'Gorman's statement at the end of his remarks "that a D.P. switch is always used which disconnects the condenser from the circuit while breaking it," I think it is more usual in the case of high tension feeders to employ single-pole switches (Ferranti switch

gear), though even when D.P. switches are used it can easily be seen that they would not prevent some considerable capacity from still *directly shunting the switch contacts.* Another case in which capacity directly shunts the contacts is that of a switch in a substation which joins the inners of two concentric cables. The insulation resistance of high tension cables will in general be several megohms, so that there will not be sufficient leakage to reduce the danger. Mr. Duddell.

In low tension networks the dangers are much less; probably the worst are those due to a short circuit or to a large motor failing to start up, resulting in the action of some automatic cut-out or fuse whose contacts, or those of the short circuit itself, are practically directly shunted by part of the capacity of the system. If the capacity is shunted by a non-inductive resistance as low as 100 ohms I should certainly expect the danger to be very small.

5. Without further experiment I am unable to say what is the puncturing effect of the rises in P.D. I have observed, as I have always had to be most careful to keep the rises well under control to avoid breaking down the condensers. One thing is, however, quite certain, and that is that even with experiments on such a small scale as those described in the paper the puncturing effect is considerable.

There is one other point which I have not yet alluded to, and that is the question as to whether a distributed capacity such as that of a concentric cable will behave the same as a condenser. It was this doubt which led me to put my suggestion of the possible danger to cables in the form of a question. Owing to the courtesy of Mr. Minshall I have been able to test this point experimentally with an actual cable under more nearly practical conditions, and I find that the rises in P.D. do take place when using the distributed capacity of a concentric cable.

Mr. Trotter alludes to the extreme sensibility of the arc to small variations in the current through it. Since writing the paper I have heard of another rather interesting example of this sensibility. Whilst I was making experiments on the Musical Arc at the Central Technical College, obtaining my current from the street mains, Mr. W. Bradfield noticed that an arc, with which he was working in Sir W. de W. Abney's laboratory, and which was also supplied by the street mains, was playing a tune.

Thus this latter arc, which was burning under ordinary conditions and was not adjusted in any way to make it sensitive, detected the effect, on the distributing network of a large supply station, produced by my Musical Arc taking a current which was varying by about half an ampere from the mean, although the two arcs were in totally distinct buildings, at a distance, in a straight line, of about 400 yards from one another, and at a considerably greater distance if measured along the street mains.

Mr. Trotter is quite correct that the model of the humming arc shown at the meeting was greatly exaggerated, but this was necessary to make the effect visible to those at the back of the lecture hall. When I said that the light varies, I thought that I had made it clear that the light to which I referred was that given out in the direction of my lens,

Mr. Duddell. as I use at the end of my section on the humming arc the expresssion "the light emitted in a given direction." In order to make this quite clear I have inserted the words "in a given direction" into my conclusions at the end of the paper.

It is admitted, I think, that the humming arc rotates. Suppose it is once started in rotation, it cannot continue so without some force or forces are acting on it tending to maintain the rotation. The question is, what is the nature of these forces? At first sight there are two possible causes outside the arc itself which may tend to maintain the rotation and humming. I refer to convection currents of air and to the effect of a magnetic field. The first of these does not seem to be the true explanation, as the arc will hum in any position even with the carbons horizontal; the second, the magnetic field, is also for a similar reason excluded; in fact, the arc will still hum even if deflected to one side of the crater and kept there by means of a magnet. So that neither of these causes seems able to supply a satisfactory explanation of the rotation of the arc observed when humming.

Within the arc itself there is a possible cause for the rotation, viz., if the arc is burning between any two points, and there exist contiguous to them any two other points between which the current would do less work in maintaining the arc, then the arc will tend to move from between the former to between the latter points—that is, under ordinary conditions the arc will tend to move to between those points requiring the lower P.D. Suppose the arc is rotating, I will call the side of the spot where the current passes from the carbon to the gas, which *leads* in the direction of rotation, and which is constantly moving to points on the end of the carbon through which no current was passing, the *leading side*. In order that the arc may continue to rotate, it is necessary that the leading side should be moving into successive positions which require less P.D. to maintain the arc than do the other sides. There are three possible causes of such an effect. (1) The ends of the carbons may be nearer together at the leading side than elsewhere. (2) The oxygen of the air may obtain better access to the leading side, either directly or by being absorbed in the carbons. (3) The temperature gradient at the leading side may be different to elsewhere. Of these (1) does not seem to be the true cause of the rotation, as the arc will often move from burning between points at a shorter distance apart to between those at a longer; though a variation in distance in conjunction with the rotation of the arc may well be the cause of the observed variation in P.D. and current. (2) The direct access of the oxygen of the air to the hot carbon and its combination with it would seem to tend to stop the rotation, as it would be less likely to combine with the cooler carbon at the leading side and produce a drop in P.D. there, such as Mrs. Ayrton discovered in her experiments on hissing, than to combine with hotter carbon at the other sides. It is difficult to say whether the oxygen absorbed in the carbon would behave in the same way. (3) The possible less temperature gradient at the leading side seems to me one of the most probable causes of the rotation, though considerably more experimental evidence as to its effect on the P.D. required to maintain the arc is necessary before any very definite

opinion can be expressed. If the opportunity offers I hope to continue my experiments on humming along this line. Mr. Duddell.

In conclusion, I wish to express my thanks to the members of the Institution for the very kind way in which they received my paper. I wish also to thank Messrs. G. Wall, L. Murphy, R. M. Moberly, and J. F. Hunt for the untiring way in which they helped me to prepare and carry out the experiments shown at the meeting.

The PRESIDENT: I will now ask you to give a vote of thanks to Mr. Duddell for his paper. I really do think we have had the most extraordinary luck this session with regard to having good papers, and I think this is one of the best. The President.

The vote was carried with acclamation.

The Three Hundred and Fifty-Fifth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, 25, Great George Street, Westminster, on Thursday evening, December 20th, 1900, Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on December 13th, 1900, were read and approved.

The names of new candidates for election into the Institution were announced, and it was ordered that they should be suspended.

The following transfer was announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

Francis E. Procter.

Donations to the Library were announced as having been received since the last meeting from Mons. G. Eiffel, to the Building Fund from Messrs. J. S. Highfield, G. F. R. Jacomb-Hood, and R. H. Sperling, and to the Benevolent Fund from Mr. J. S. Highfield, to whom the thanks of the meeting were duly accorded.

Messrs. Hal Williams and Alan Williams were appointed scrutineers of the ballot for the election of new members.

The following paper was read :—

THE ELECTRICAL ENGINEERS R.E. IN SOUTH AFRICA.

By LIEUT.-COLONEL R. E. CROMPTON, E.E. (R.E.) V., Past-President.

At the request of your President I have prepared a narrative of the war services of the small body of electrical engineers who left England early in the spring of this year for South Africa and who have now returned.

I must commence by reminding you that the corps of Electrical Engineers R.E. Volunteers was raised by the help of this Institution in order to enable electrical engineers to place their services at the disposal of the country in case of need. It is acknowledged that every year electrical appliances will be more and more used in military operations. Up to last year the special work on which the corps had been instructed and drilled for home service has been the management of the searchlight apparatus used at various points for coast defence, to which has been added some instruction in submarine mining and cognate matters.

As both officers and men of the corps felt that the training which every one in the electrical profession must go through has made us all handy men, not only for electrical, but for general mechanical engineering work, we offered our services for the war in South Africa. Our offer was accepted in December, 1899, and after some consultation with the War Office an equipment was designed by our own officers and was manufactured with such rapidity that our first detachment was ready for embarkation early in March.

Five officers and forty-seven men were mobilised in February, and on the 16th of March five officers and forty-seven men embarked from Southampton on ss. *Tagus*. On the 17th two officers and one non-commissioned officer embarked on the *Custodian* in charge of the equipment. The equipment has already been described in the technical journals; I will remind you that it consisted of portable searchlights mounted on carriages somewhat similar to those used for field artillery guns, the electrical energy being generated by dynamos carried on small compound steam traction engines. Special cable carts were also provided.

I do not propose to take your time in giving the details of construction of the projectors, engines, dynamos, or other apparatus; those interested in these matters will have full opportunity of examining it in March next, when the headquarters of the corps are completed.

Although steam traction engines were chosen, it was foreseen that the oil engines to which the corps is so well accustomed at its annual trainings would have had

great advantages if a portable type of oil engine had been procurable.

A supply of arc lamps, with special lanterns which could be readily packed, and incandescent lamps with fittings, were also sent out for the electric lighting of working parties, depôts, and railway sidings.

A novel feature of the equipment was that twenty bicycles were provided with reels on which fine, uninsulated copper wire was coiled, to serve as telephone conductors, and a special light and very portable type of telephone was obtained, which, as will be seen hereafter, gave excellent results.

The whole of the remainder of the equipment, which contained, among other things, complete sets of repairing tools, tube wells, pumps, and portable forges, was carefully considered, and subsequent experience showed that it was well chosen.

The *Tagus* arrived at Cape Town on the 4th, and the Unit disembarked on the 6th and were encamped at Fort Knokke for a few days. The *Custodian* arrived on April 12th, and the equipment, including two of the 8-ton traction engines and four 5-ton waggons, were unloaded that night.

Colonel Girouard, the Director of Railways, at once applied to have the Electrical Engineers attached to the railway re-construction trains, and they were ordered to get ready to move up country as quickly as possible. On Saturday night, the 14th of April, the whole of the equipment was packed on five large bogey trucks, but even their start seemed likely to be delayed as the line was blocked with press of traffic. Under these circumstances the Unit received an invitation from the Electrical Engineers of Cape Town to attend a smoking-concert to be given in their honour on the following Tuesday, but unfortunately this could not be accepted, as on Monday morning the Unit suddenly got orders to start.

After a journey of three days and four nights it arrived at Bethulie at 5 a.m., 20th of April, and at once off-loaded the equipment, and within a few hours the first installation of temporary electric light for war purposes was erected on the Bethulie road bridge, which was then temporarily in use for railway purposes, during the time that the low-level deviation railway bridge was then constructed by the Railway

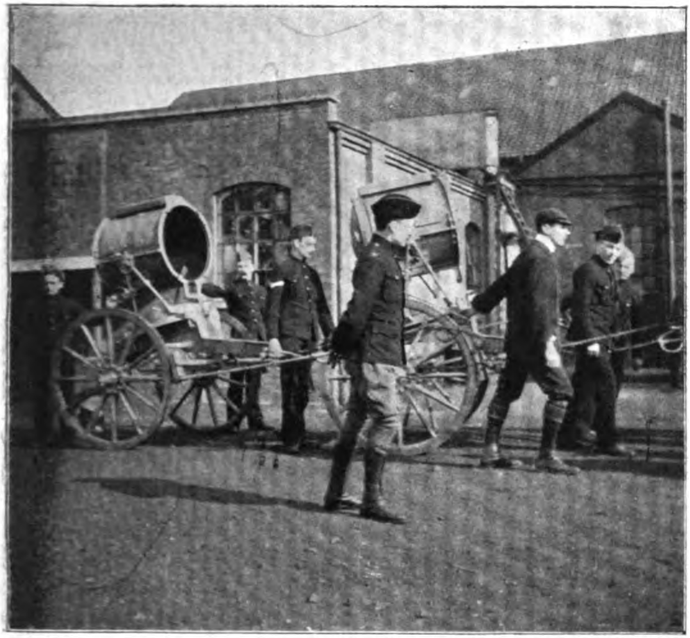


FIG. 1.—E. E.-pattern Portable Searchlight with Drag-ropes.

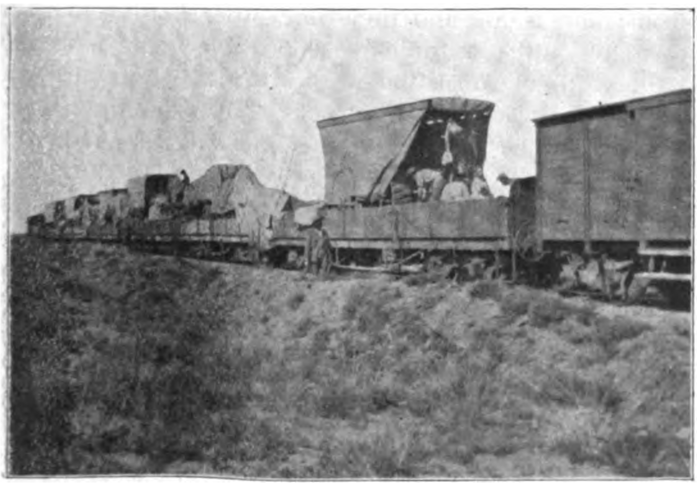


FIG. 2.—Train showing Engine on Truck.

Pioneer Regiment to replace the original railway bridge which had been destroyed by the Boers.

At first six arc lamps were found sufficient, and these were erected and worked nightly from one of the dynamos mounted on its traction engine at the river-bank. As soon as the low-level railway bridge was completed the installation on the road bridge was dismantled and transferred to the new bridge, the approaches to which, being tortuous and having steep gradients, had to be worked by the engine drivers with the greatest caution, so that for some days the arc lights were used to light these approaches.

The first time the field telephones were put to work was at this place. A line was laid across the bridge for the use of the railway, and a good telephone service established.

During the time that the corps was at Bethulie Sergeant-Major Brown, R.E., and Sapper Phillips, E.E., were sent out with part of the telephone equipment to accompany a flying column which left Bethulie on May 2nd to join General Hart, who was then moving south from Smithfield. As the telegraph line between Bethulie and Smithfield had been destroyed the new field telephones were brought into use to maintain communication with the flying column, and this was kept up without any failure during the time the column advanced until it met General Hart. General Hart was thus enabled to be put into communication with Lord Roberts *viâ* Bethulie, temporary communication being made between General Hart's camp, one and half miles from the telegraph line, by bare copper wire No. 22 gauge laid on the ground from the bicycle reels supported by a special belt to the body.

On the 6th of May the Unit arrived at Bloemfontein and was split up into two sections, one going on direct to Rail-head, which was then at Vet River, the other section remaining at Bloemfontein to carry out the electric lighting of the goods yard and locomotive shops. At this point an installation of arc and incandescent lamps was erected and worked by No. 1 engine and dynamo, and has been running ever since, the installation being gradually increased in size until there are now sixteen arc lamps and a large number of incandescent lamps installed. It must be noted that it is somewhat of a feat to carry out a temporary job of railway lighting of this kind, and to work it continuously

Pioneer Regiment to replace the original railway bridge which had been destroyed by the Boers.

At first six arc lamps were found sufficient, and these were erected and worked nightly from one of the dynamos mounted on its traction engine at the river-bank. As soon as the low-level railway bridge was completed the installation on the road bridge was dismantled and transferred to the new bridge, the approaches to which, being tortuous and having steep gradients, had to be worked by the engine drivers with the greatest caution, so that for some days the arc lights were used to light these approaches.

The first time the field telephones were put to work was at this place. A line was laid across the bridge for the use of the railway, and a good telephone service established.

During the time that the corps was at Bethulie Sergeant-Major Brown, R.E., and Sapper Phillips, E.E., were sent out with part of the telephone equipment to accompany a flying column which left Bethulie on May 2nd to join General Hart, who was then moving south from Smithfield.

As the telegraph line between Bethulie and Smithfield had been destroyed the new field telephones were brought into use to maintain communication with the flying column, and this was kept up without any failure during the time the column advanced until it met General Hart. General Hart was thus enabled to be put into communication with Lord Roberts *viâ* Bethulie, temporary communication being made between General Hart's camp, one and half miles from the telegraph line, by bare copper wire No. 22 gauge laid on the ground from the bicycle reels supported by a special belt to the body.

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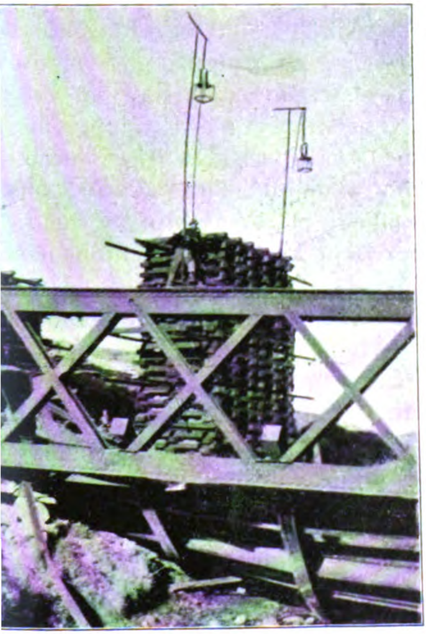
Bridge (Zand River) as left by Boers.



ge, showing Girder down, and Arc-lighting.

without any failure or interruption from May to December (*i.e.*, up to the date of writing), using only one engine with no spare plant, and the credit of this excellent service must be mainly given to the small detachment that was left at Bloemfontein under command of Corporal Bicker Caarten, to whom has since been entrusted the design for a permanent installation to replace this temporary plant.

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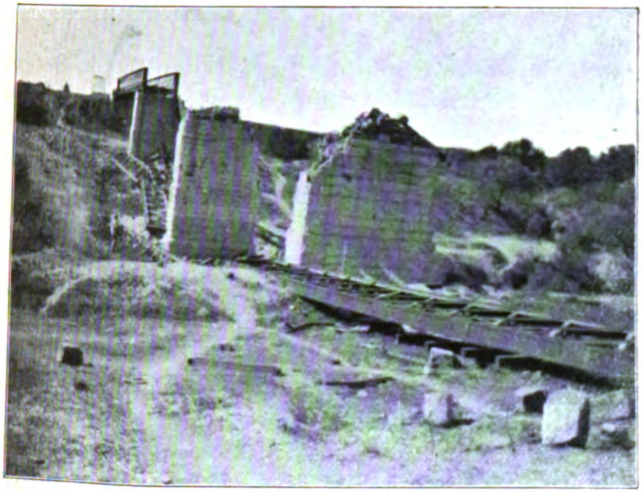

FIG. 3.—Destroyed Bridge (Zand River) as left by Boers.

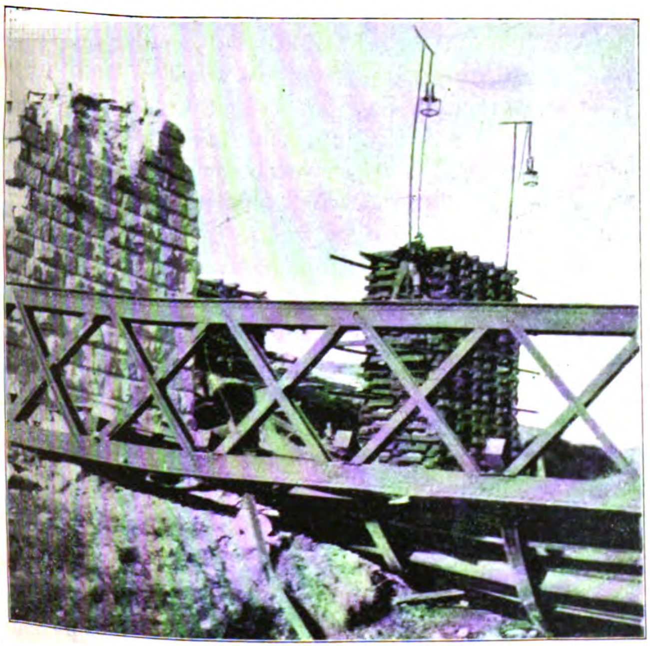

FIG. 4.—Rhenoster Bridge, showing Girder down, and Arc-lighting.

FIG. 5.—Sergeant Phillips levelling Timber Beams.

Early in May Colonel Girouard required the services of additional railway telegraph men, and Captain Bain was detailed for this work and with a detachment of seven men was sent on to repair the telegraph in advance of Railhead. This was a service of great importance, entailing considerable personal risk and exposure.

When the advance of Lord Roberts upon Bloemfontein began, the Electrical Engineers were asked to repair the railway telegraphs, conjointly with the repair of the railway itself. Captain Bain's party did their work so expeditiously and well that they were never once overtaken by the first Construction train throughout the whole of the Orange River Colony. The gaps in the wires were sometimes several miles long, poles smashed and wires cut up, necessitating, in most cases, entire reconstruction. The work done by the Electrical Engineers was *permanent*, not temporary work. The poles were iron, twenty-two feet long, and the wire used was No. 8 wire. The party had to transport their baggage and rations themselves as well, and not the least of their officer's trouble was getting the heavy poles and wire to the places required so that the work would never be delayed for a moment—and it never was delayed.

It need be remembered that this party was working ahead of the first Construction train and had to depend upon bullock waggons and trolleys for transport.

The detachment, on reaching Vaal River, finished their work so far as the Orange River Colony was concerned, by restoring the wires which the enemy had cut. Engineers will appreciate the work of getting No. 8 wire across a deep and wide river without boats or proper appliances. (They found an old boat with numerous holes in it but no oars, and utilised it.) The river span of wire is over 300 yards wide.

Besides restoring the telegraphs, a *railway* telephone system was established. This was necessary owing to the want of sufficient men to work the telegraph instruments. This telephone service was entirely carried out by the Electrical Engineers. In addition the elaborate Electric Block system was restored, and the Electric gong signal system.

The telegraphs on the new railway between Johannesburg and the Orange River Colony were constructed by the Electrical Engineers, and lastly, time after time, when most of the wires in the country had been systematically cut by

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the enemy, the Electrical Engineers restored the communications so quickly that practically no delay occurred in transmission.

We should also mention that the telegraph instruments found in the Transvaal were all of the "closed circuit" pattern (requiring the key to be lifted up instead of pressed down, as in the English pattern). The Electrical Engineers converted them to the open circuit—not an easy matter for men only provided with screwdrivers, knives and pliers of their belt equipments.

Captain Bain, who was eventually assisted by Lieutenant O'Shaugnessy, remained at this work for several months and eventually was put in charge of the whole of the railway telegraphs in the Transvaal under Captain Manifold, R.E., Administrator of Railway Telegraphs, his detachment being strengthened from time to time by additions from this Unit, as well as from the Royal Engineers and other corps.

The No. 1 section commenced lighting work at Zand River on the 18th of May, this work being of a very similar nature to that of the Vet River. It afterwards advanced with the Railhead Construction trains to the Rhenoster Spruit to assist the working party building a crib bridge at that point. Here a particularly smart piece of lighting work was carried out. The orders were received at 2 p.m. The traction engine was off-loaded from its truck and hauled its waggons and stores down to Rhenoster Spruit three miles away, the light stores going down the damaged railway line on a trolley. Eight arc lamps were fixed on poles and light was furnished to the working party by nightfall, 5.30 p.m.

The new and first reconstructed bridge at Rhenoster was completed on the 29th, and there being then no large work ahead requiring arc lights, the detachment went forward with the construction train and were employed principally on the actual work of building the crib piers, fixing the beams and laying the rails until the line was completed and railhead advanced to Taibosch. During this time the equipment was left behind at Roodeval in charge of Sergeant Phillips.

During the next eight days the detachment had an exciting time, as the enemy under De Wet and Theron were threatening the line and reconstruction works. The electrical engineers formed part of the reconstruction day

shift, the working hours being generally from 6 a.m. to 6 p.m., but sometimes up to 12 midnight, so that on these days the men were eighteen hours consecutively at work.

From Rhenoster up to Taibosch the enemy at the advice of Theron had destroyed the line very completely, not only the larger bridges, but all the smaller culverts were blown up; in some places the rails for considerable distances were twisted and contorted by dynamite cartridges fired at every fish joint.

On Wednesday, 6th of June, Taibosch Spruit was reached, and seeing that arc lights would again be required at this point and at the Vaal River, Captain Lloyd was sent back with two engines and a few trucks to bring forward the electric light equipment which had been left at Roodeval. His journey down the threatened line to Roodeval was a most exciting one. At Vredefort Weg he was called upon to arrest the Field Cornet Le Roux, who, although he had taken the oath of allegiance, had been observed signalling to the enemy. This train was expected to be attacked at any point south of this, and the utmost precautions had to be taken. As the water supply at Roodeval was known to be scanty he left one locomotive to fill up its tanks at Rhenoster and took one on to Roodeval. He there found that the small garrison had been threatened for days, and had been on harassing night duty during that time.

On his approach to Rhenoster Spruit he found that the line was blocked by some trucks which were being used, somewhat irregularly, for shifting tents and camp equipment required for a new camp.

As Captain Lloyd knew that De Wet was preparing to cut the line to the north of Rhenoster this delay seemed likely to result in the Unit losing their electrical equipment. As it was the line was only cleared in time to get the train away a few hours before De Wet commenced his attack on the Rhenoster camp, which resulted in heavy losses and in the destruction of the new bridge, the water supply, and of the valuable ammunition and stores then at Roodeval.

The return journey northwards was of the most exciting nature. The train was made up with some of the trucks in front of the locomotive, so that in case of the leading truck being derailed it could be thrown off more easily and thus less delay caused than if the locomotive itself were derailed.

It was necessary to examine the track with lamps placed on the leading truck, and thus by lamp signalling back to the engine driver to control the running of the train. In this manner the train was worked back to Taibosch.

At Vredefort Weg Captain Lloyd arrested and brought along with him the Field Cornet Le Roux. By the time Captain Lloyd passed Vredefort Weg De Wet had been successful in his attack at Rhenoster and cut both railway and telegraph wires, so that the construction trains were entirely cut off from the south.

During the time that the arc lights were being used on the bridge at Taibosch on the nights of the 7th and 8th Lieutenant Pott succumbed to enteric fever. This was a great loss to the Unit, as this officer had himself designed a great portion of the arc lighting and projector plant, and the loss of his services greatly crippled the Unit. He had to be left at Viljeonsdrift, where he was nursed with extreme care by Dr. and Mrs. Dixon, Dr. Dixon being the medical officer to this section of the railway.

Here Sapper Weakey also fell ill of enteric fever, probably brought on by the exposure at Roodeval. He lingered for some time, and eventually died at Viljeonsdrift on the 27th.

During the time that the Unit was at Taibosch Major Crompton, taking with him Sergeant-Major Brown, R.E., and Companys Sergeant-Major Rorke, went south with the field telephones to attempt to make temporary communication at the point where the telegraph lines had been cut by the Boers. Major Crompton returned to his command at Taibosch, leaving the two non-coms. with Lord Kitchener, who arrived at Kopjes on the 9th. They were able to establish communication with the south, and thus kept him in touch to north and south until the telegraph lines were again in working order.

Railhead reached the Vaal River on the 10th of June, and at this point an installation of twelve lamps was erected, and on the 11th the first train crossed into the Transvaal and some supplies were sent to Lord Roberts at Pretoria.

It may be here remarked that as during the advance of railhead from Bethulie to the Vaal the arc lamps were worked on nineteen nights, it is probable that the period of reconstructing the line was shortened by nearly the same

number of days, but even if one night's work is only considered to be equal to two-thirds of a day's work the night work rendered possible by the section must have hastened the advance of railhead by not less than twelve days, and the money value alone of this to the nation must have many times repaid the entire cost of equipping and sending out the Electrical Engineers.

After one night's lighting at the Vaal the very thorough destruction of the line to the south by De Wet necessitated the sending south for a second time both construction trains; the Unit accompanied them, leaving the lighting equipment at Viljeonsdrift under Sergeant Brown.

The construction trains working south were constantly threatened by De Wet, and on the night of the 14th of June both trains were attacked by him, and were summoned to surrender.

As this was the first occasion on which the Electrical Engineers were under fire, perhaps I may be permitted to describe the attack at some length :—

Very early in the morning of the 14th of June the night working party, which consisted chiefly of Royal Engineers and volunteer Royal Engineers, none of them being Electrical Engineers, were at work rebuilding the crib piers of the recently constructed bridge at Leuwspruit; at this time one of the construction trains was drawn up close to the working party, who were at the break in the line, the other train being about half a mile to the north on its way to shunt empty trucks on a siding a mile further north.

The first trouble noticed was the derailing of the leading truck of the northern train. This was caused by a stone having been wedged by the Boers between the main and the guard rails. As soon as the train was pulled up it was fired on by an attacking party which apparently surrounded it. The troops on the train promptly replied, and with good effect, as the Boers drew off after half an hour's firing and concentrated their attack on the other party at the Spruit, but during this sharp attack the vans and coaches of the northern train were riddled by bullets, and those sleeping in them had narrow escapes. The attack coming at first from the south side, the engine driver started to move the engine northwards. The Boers then made a rush on the unarmed working party, who, with one officer and sixty

men were taken prisoners; the remainder, however, escaped, but could not rejoin the party defending the trains.

The Electrical Engineers had formed the day-working party, and having been many hours at work, and consequently very tired, were sound asleep. Those of them who were sleeping outside the trucks, close to the working party, were captured by the Boers before they were able to regain the train. At this time the Boers' firing was very heavy, and three officers, *i.e.*, Lieutenant Micklem, R.E., Lieutenant Bigge, E.E., and Lieutenant Holmes, of the Royal Irish, were seriously wounded. Three sappers were killed, the engine driver and a number of others seriously wounded, and of the native workmen about thirty were killed or wounded. At this time De Wet sent in a messenger summoning the train to surrender as the Boers were greatly superior in force and had guns. No attention was paid to the message, and the remaining troops, who were then under the command of the officers of the Electrical Engineers, took up a position on a ridge of rocks which ran transversely to the train, from which the train could be protected without the men being exposed. This position was held for several hours—in fact, up to daybreak—the firing of the Boers being continuous and severe. On the other hand, the position we occupied was so strong that the Boers were unable to approach the train, and soon after daybreak they withdrew from the attack.

Towards the latter part of the time the Boers were much disconcerted by the shrapnel which was fired over them by two guns placed by Lord Kitchener in a position to the south.

The night was intensely cold and trying to every one; the whole of the defending party were asleep in the trucks when the attack commenced. Although taken at such a serious disadvantage, every man on the train, without distinction, behaved as coolly and quietly as if there were no enemy present.

It was a difficult matter even for old and trained soldiers to free themselves from the crowd of Basutos who formed the native working party, and who cleared out from the train at the commencement of the firing, but, in spite of this, there was no confusion; ammunition was quietly served out, and our men got into such strong positions that it was impossible

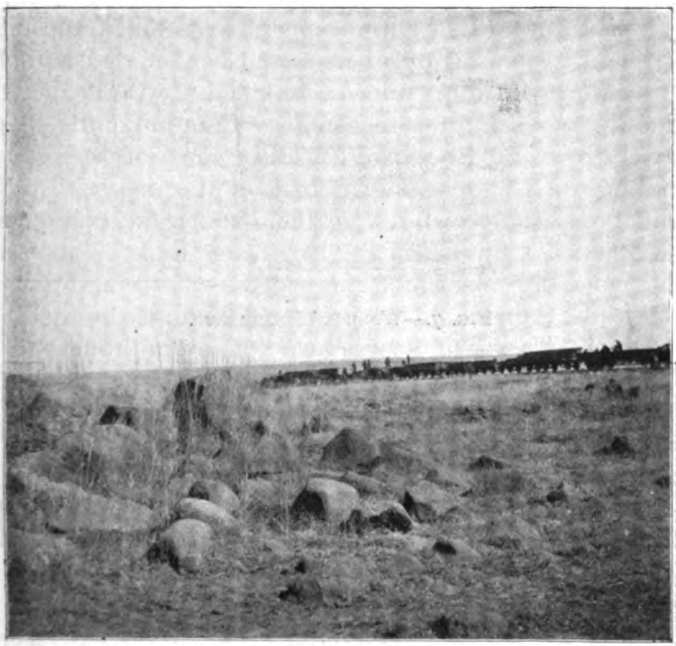

Fig. 6.—Scene of Action at Leeuwspruit.

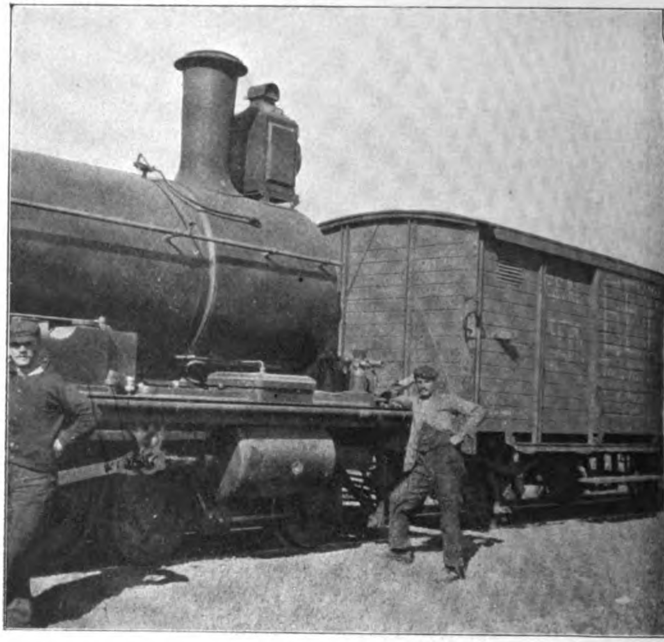

FIG. 7.—Wounded Locomotive.

FIG. 8.—Firing from Van.

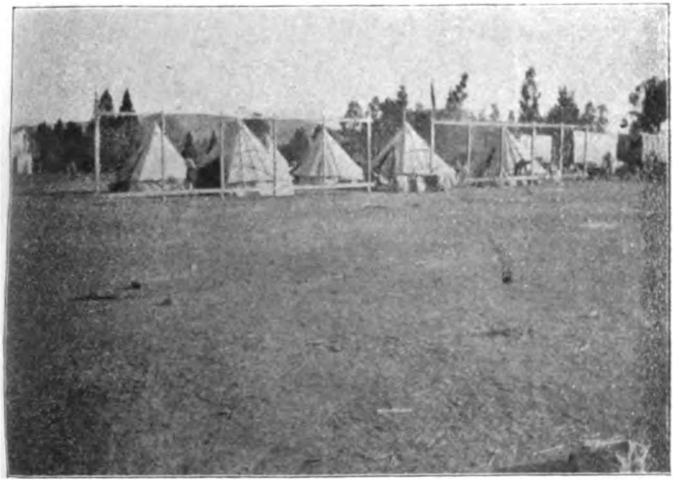

Fig. 9.—E. E.-Camp at Pretori

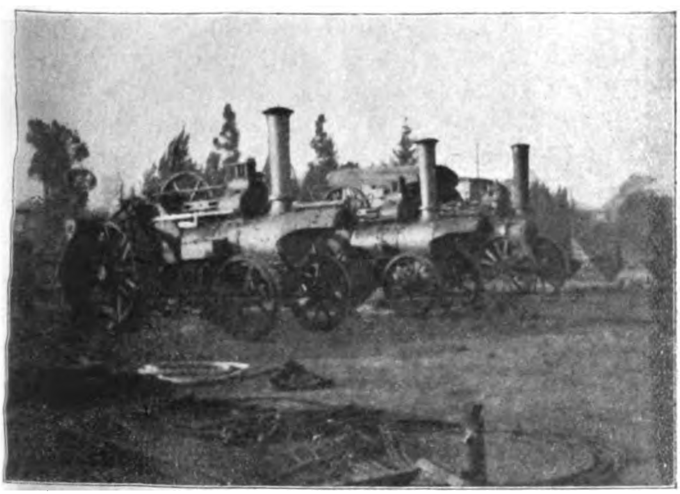

Fig. 10.—Park of Engines.

for the Boers to make their attack successful. Every one behaved so well that it is difficult to single out any one present for special praise. Although the Electrical Engineers engaged on this occasion were comparatively a small party, yet, owing to so many of the night-working party having been surprised and dispersed in the first instance, they formed nearly one-third of the troops left to defend the trains. If De Wet had been successful in catching and destroying these two trains, which contained so much construction material and all the tools, as well as the most skilled body of reconstruction officers, the break in the line of communications would have remained open for a long period, and certainly would have seriously affected the future movements of the more advanced portion of the Army then in the Transvaal.

This attack caused the Electrical Engineers to temporarily lose the services of one officer wounded, and Corporal Sellon and six Sappers taken prisoners. The remainder went south with the construction trains to Rhenoster, and assisted in the building of this important bridge. Whilst there, orders were received from Army Headquarters, that the whole of the Electrical Engineers should come up to Pretoria at once. They started on the 20th, leaving Lieutenant O'Shaughnessy to complete a system of telephones connecting Rhenoster Camp, Leuwspruit, Roodeval, and other points which had been recently threatened or attacked by De Wet. After carrying out this work he joined the headquarters at Pretoria on the 26th of June.

After arriving at Pretoria, the Engineer-in-Chief found quantities of electrical work for the corps, as all the forts which defend the town had been fitted up with various electrical apparatus, not only for electric lighting but there were signal signalling, telephone and other wires, which required to be sorted, labelled, and their uses understood.

The oil engines which supplied the motive power for driving the dynamos had purposely been damaged by the Boers, and had to be repaired and set to work. The small and inefficient searchlights which had been used by the Boers were replaced by a system of incandescent lamps placed so as to illuminate certain points which were liable to be threatened by the enemy during night attacks.

This work at the forts, which was of a very interesting

nature, was followed by teaching the garrisons how to use and maintain the electrical apparatus in working order.

Other parties of our men were employed in fitting up electrical lighting in various public buildings which served as supply stores, and in the large hospitals which were then being started, inside and outside Pretoria. In some cases these new installations were worked from the public supply of the town, in other cases separate generating machinery, *i.e.*, steam engines, dynamos, and systems of conductors had to be put down for each job. The plant for this was made up from material found at or near Pretoria, most of which was in a damaged condition and had to be almost re-made before it could be usefully employed.

During this time, as the whole of the Rand district surrounding Johannesburg is supplied with electric light and power partly from a distant generating centre at Brak Pan, the Military Governor of Johannesburg asked for and obtained the services of Captain Leaf as his electrical adviser, and from time to time various works were supervised by him and by other officers of the Corps, so that the electrical plant of Johannesburg and district was gradually got into order.

It will be interesting to those who have read Rider Haggard's novel, "Jess," to know that the camp at Pretoria was close to the site of Jess's cottage.

Its position was well chosen; a stream of water was handy for washing out the engines and it was close to the railway and railway workshops. Thus, it was in a most convenient position for repairing the various pieces of apparatus that they were installing in the forts and public buildings. Amongst others, the Government Printing Works of Pretoria, worked by their own electric generating plant transmitting power to motors driving each set of printing machinery, was put in order and worked by the Electrical Engineers.

Early in July, Electrical Engineers were several times called upon to extricate an engine which it was proposed to use to haul 12-ton 6-in. quick-firing guns to various positions near Pretoria. This engine and a gun were hauled out of a drift almost in the middle of Pretoria, into which it had sunk in the course of an experimental run.

A few days later, after the driver of this engine had placed

the gun in position near Deerdepoort, he took his engine down to a spruit in order to fill up his water tanks, but approached too closely to the soft ground, so that the engine turned over on its side and could not be got out until we were sent for.

Great praise is due to Captain Lloyd and Captain Leaf and the detachment engaged on this work, which was carried on throughout the night. The way in which the Electrical Engineers handled the engines and gun made it evident to the officer commanding the artillery that the Electrical Engineers were so capable, that he placed the engine and the two guns in their charge, and the subsequent work of placing these, the heaviest guns ever taken into the field, was carried out by the officers and men belonging to the Corps.

On the 24th of July, a 6-in. quick-firing gun, weighing with its carriage 12½ tons, was hauled to the top of Quagga Kop, seven miles to the west of Pretoria, and 1,300 feet above it; the average slope up which the gun was hauled was 1 in 10, but there were point parts of it which were steeper.

On the 1st of August a similar gun was hauled up a slope averaging 1 in 6, and in some places 1 in 5, to a redoubt on the top of this hill, about five miles east of the town. A few days later two large traction engines belonging to the Director of Steam Transport were put under our charge, under the officers of the Electrical Engineers, and with these and the other three engines, making five traction engines, a regular daily service was organised, and stores of every description were transported to various points, chiefly to the westward of Pretoria, the longest run being to Commando Nek, twenty-six miles distant, where a depôt was formed for flying columns. The service on this road lasted for many weeks, in fact, up to the time the Corps started for England, and was carried out without any mishap or loss, although during the whole of the time the line was threatened by the Boers, and we were informed that sniping frequently went on, but as far as we were concerned no one was hit. A new system of escorts was adopted; sufficient men to form two or more escorts being put under the command of the officers of the Corps and encamped with us.

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As the telegraph line between Bethulie and Smithfield had been destroyed the new field telephones were brought into use to maintain communication with the flying column, and this was kept up without any failure during the time the column advanced until it met General Hart. General Hart was thus enabled to be put into communication with Lord Roberts *viâ* Bethulie, temporary communication being made between General Hart's camp, one and half miles from the telegraph line, by bare copper wire No. 22 gauge laid on the ground from the bicycle reels supported by a special belt to the body.

On the 6th of May the Unit arrived at Bloemfontein and was split up into two sections, one going on direct to Railhead, which was then at Vet River, the other section remaining at Bloemfontein to carry out the electric lighting of the goods yard and locomotive shops. At this point an installation of arc and incandescent lamps was erected and worked by No. 1 engine and dynamo, and has been running ever since, the installation being gradually increased in size until there are now sixteen arc lamps and a large number of incandescent lamps installed. It must be noted that it is somewhat of a feat to carry out a temporary job of railway lighting of this kind, and to work it continuously

Pioneer Regiment to replace the original railway bridge which had been destroyed by the Boers.

At first six arc lamps were found sufficient, and these were erected and worked nightly from one of the dynamos mounted on its traction engine at the river-bank. As soon as the low-level railway bridge was completed the installation on the road bridge was dismantled and transferred to the new bridge, the approaches to which, being tortuous and having steep gradients, had to be worked by the engine drivers with the greatest caution, so that for some days the arc lights were used to light these approaches.

The first time the field telephones were put to work was at this place. A line was laid across the bridge for the use of the railway, and a good telephone service established.

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without any failure or interruption from May to December (*i.e.*, up to the date of writing), using only one engine with no spare plant, and the credit of this excellent service must be mainly given to the small detachment that was left at Bloemfontein under command of Corporal Bicker Caarten, to whom has since been entrusted the design for a permanent installation to replace this temporary plant.

The advance section at Vet River joined the reconstruction trains and remained with them during the months of May and June—*i.e.*, until the work of reconstructing the railway was completed through the Orange Free State up to the Vaal River.

The equipment of this No. 1 section consisted of No. 2 traction engine with its dynamo, two waggons, subsequently increased to four waggons, two projectors with their limbers, two cable carts, extra cable coiled on drums, sixteen arc lamps with suitable poles, hoisting gear and the necessary accessories, a supply of incandescent lamps with suitable fittings, fourteen sets of field telephones, a supply of insulated and bare copper wire telephone conductors coiled on reels which could be either carried on the bicycle or on special slings strapped to a man's chest in such a position that he could either pay out or wind up a conductor.

The work at Vet River may be taken as typical of many other works at which it was necessary to work all night by artificial light. The Railway Construction Corps R.E. was engaged in constructing a main bridge across the river approached by long deviations from the main line; in these were three smaller bridges. The lighting plant had therefore to be erected at each of these bridges in turn.

When the Vet River work was completed the section moved on to Smaldeel, and there was joined by me with a draft which had left Cape Town on the 4th of May. I brought with me a third traction engine with its dynamo, an additional supply of concentric cable, two additional 5-ton waggons, stores, bicycles, &c., and then took over command of the Unit.

As occasion arose, the whole of the Bloemfontein section with their stores was gradually moved up to join the headquarters of the Unit, leaving only a small detachment of six men under the command of Corporal Bicker Caarten, to work the temporary lighting plant at Bloemfontein.

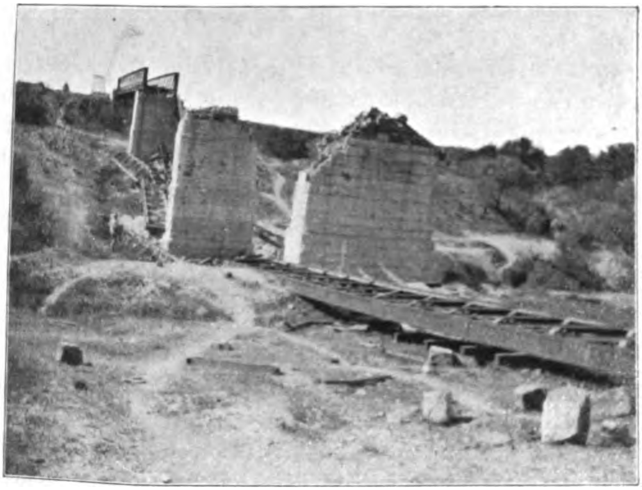

FIG. 3.—Destroyed Bridge (Zand River) as left by Boers.

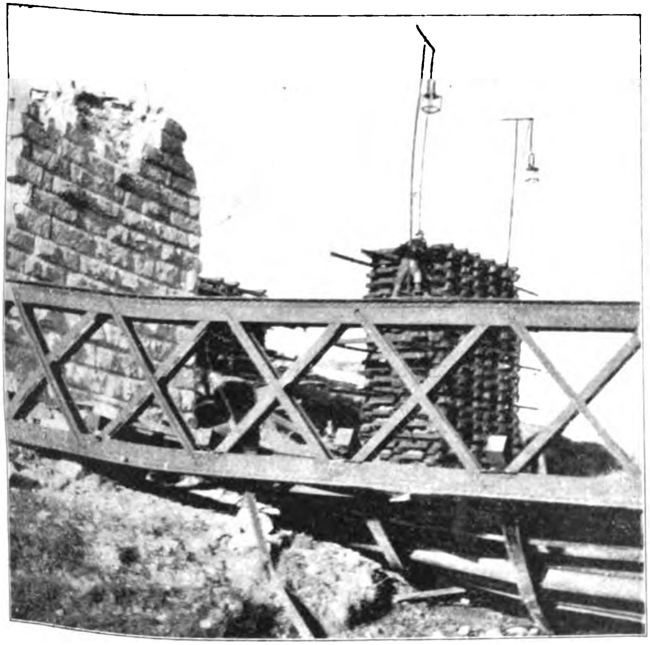

FIG. 4.—Rhenoster Bridge, showing Girder down, and Arc-lighting.

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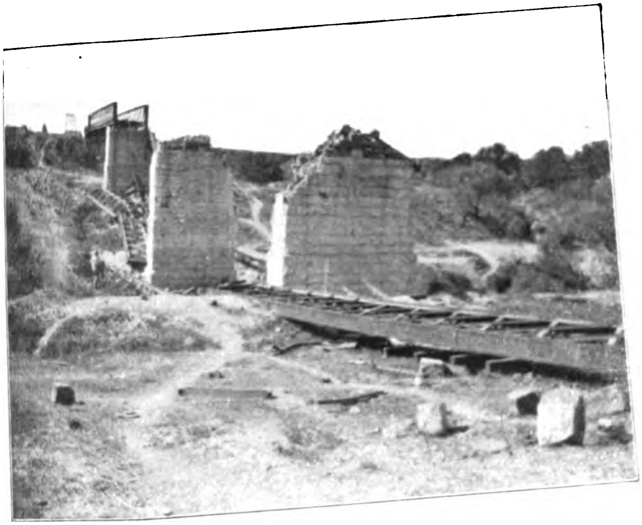

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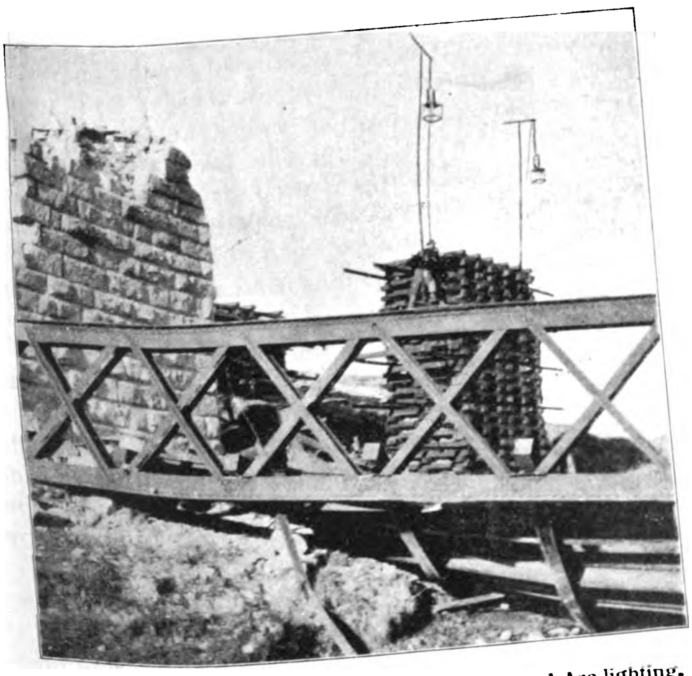

FIG. 4.—Rhenoster Bridge, showing Girder down, and Arc-lighting.

FIG. 5.—Sergeant Phillips levelling Timber Beams.

Early in May Colonel Girouard required the services of additional railway telegraph men, and Captain Bain was detailed for this work and with a detachment of seven men was sent on to repair the telegraph in advance of Railhead. This was a service of great importance, entailing considerable personal risk and exposure.

When the advance of Lord Roberts upon Bloemfontein began, the Electrical Engineers were asked to repair the railway telegraphs, conjointly with the repair of the railway itself. Captain Bain's party did their work so expeditiously and well that they were never once overtaken by the first Construction train throughout the whole of the Orange River Colony. The gaps in the wires were sometimes several miles long, poles smashed and wires cut up, necessitating, in most cases, entire reconstruction. The work done by the Electrical Engineers was *permanent*, not temporary work. The poles were iron, twenty-two feet long, and the wire used was No. 8 wire. The party had to transport their baggage and rations themselves as well, and not the least of their officer's trouble was getting the heavy poles and wire to the places required so that the work would never be delayed for a moment—and it never was delayed.

It need be remembered that this party was working ahead of the first Construction train and had to depend upon bullock waggons and trolleys for transport.

The detachment, on reaching Vaal River, finished their work so far as the Orange River Colony was concerned, by restoring the wires which the enemy had cut. Engineers will appreciate the work of getting No. 8 wire across a deep and wide river without boats or proper appliances. (They found an old boat with numerous holes in it but no oars, and utilised it.) The river span of wire is over 300 yards wide.

Besides restoring the telegraphs, a *railway* telephone system was established. This was necessary owing to the want of sufficient men to work the telegraph instruments. This telephone service was entirely carried out by the Electrical Engineers. In addition the elaborate Electric Block system was restored, and the Electric gong signal system.

The telegraphs on the new railway between Johannesburg and the Orange River Colony were constructed by the Electrical Engineers, and lastly, time after time, when most of the wires in the country had been systematically cut by

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We should also mention that the telegraph instruments found in the Transvaal were all of the "closed circuit" pattern (requiring the key to be lifted up instead of pressed down, as in the English pattern). The Electrical Engineers converted them to the open circuit—not an easy matter for men only provided with screwdrivers, knives and pliers of their belt equipments.

Captain Bain, who was eventually assisted by Lieutenant O'Shaugnessy, remained at this work for several months and eventually was put in charge of the whole of the railway telegraphs in the Transvaal under Captain Manifold, R.E., Administrator of Railway Telegraphs, his detachment being strengthened from time to time by additions from this Unit, as well as from the Royal Engineers and other corps.

The No. 1 section commenced lighting work at Zand River on the 18th of May, this work being of a very similar nature to that of the Vet River. It afterwards advanced with the Railhead Construction trains to the Rhenoster Spruit to assist the working party building a crib bridge at that point. Here a particularly smart piece of lighting work was carried out. The orders were received at 2 p.m. The traction engine was off-loaded from its truck and hauled its waggons and stores down to Rhenoster Spruit three miles away, the light stores going down the damaged railway line on a trolley. Eight arc lamps were fixed on poles and light was furnished to the working party by nightfall, 5.30 p.m.

The new and first reconstructed bridge at Rhenoster was completed on the 29th, and there being then no large work ahead requiring arc lights, the detachment went forward with the construction train and were employed principally on the actual work of building the crib piers, fixing the beams and laying the rails until the line was completed and railhead advanced to Taibosch. During this time the equipment was left behind at Roodeval in charge of Sergeant Phillips.

During the next eight days the detachment had an exciting time, as the enemy under De Wet and Theron were threatening the line and reconstruction works. The electrical engineers formed part of the reconstruction day

shift, the working hours being generally from 6 a.m. to 6 p.m., but sometimes up to 12 midnight, so that on these days the men were eighteen hours consecutively at work.

From Rhenoster up to Taibosch the enemy at the advice of Theron had destroyed the line very completely, not only the larger bridges, but all the smaller culverts were blown up; in some places the rails for considerable distances were twisted and contorted by dynamite cartridges fired at every fish joint.

On Wednesday, 6th of June, Taibosch Spruit was reached, and seeing that arc lights would again be required at this point and at the Vaal River, Captain Lloyd was sent back with two engines and a few trucks to bring forward the electric light equipment which had been left at Roodeval. His journey down the threatened line to Roodeval was a most exciting one. At Vredefort Weg he was called upon to arrest the Field Cornet Le Roux, who, although he had taken the oath of allegiance, had been observed signalling to the enemy. This train was expected to be attacked at any point south of this, and the utmost precautions had to be taken. As the water supply at Roodeval was known to be scanty he left one locomotive to fill up its tanks at Rhenoster and took one on to Roodeval. He there found that the small garrison had been threatened for days, and had been on harassing night duty during that time.

On his approach to Rhenoster Spruit he found that the line was blocked by some trucks which were being used, somewhat irregularly, for shifting tents and camp equipment required for a new camp.

As Captain Lloyd knew that De Wet was preparing to cut the line to the north of Rhenoster this delay seemed likely to result in the Unit losing their electrical equipment. As it was the line was only cleared in time to get the train away a few hours before De Wet commenced his attack on the Rhenoster camp, which resulted in heavy losses and in the destruction of the new bridge, the water supply, and of the valuable ammunition and stores then at Roodeval.

The return journey northwards was of the most exciting nature. The train was made up with some of the trucks in front of the locomotive, so that in case of the leading truck being derailed it could be thrown off more easily and thus less delay caused than if the locomotive itself were derailed.

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It was necessary to examine the track with lamps placed on the leading truck, and thus by lamp signalling back to the engine driver to control the running of the train. In this manner the train was worked back to Taibosch.

At Vredefort Weg Captain Lloyd arrested and brought along with him the Field Cornet Le Roux. By the time Captain Lloyd passed Vredefort Weg De Wet had been successful in his attack at Rhenoster and cut both railway and telegraph wires, so that the construction trains were entirely cut off from the south.

During the time that the arc lights were being used on the bridge at Taibosch on the nights of the 7th and 8th Lieutenant Pott succumbed to enteric fever. This was a great loss to the Unit, as this officer had himself designed a great portion of the arc lighting and projector plant, and the loss of his services greatly crippled the Unit. He had to be left at Viljeonsdrift, where he was nursed with extreme care by Dr. and Mrs. Dixon, Dr. Dixon being the medical officer to this section of the railway.

Here Sapper Weakey also fell ill of enteric fever, probably brought on by the exposure at Roodeval. He lingered for some time, and eventually died at Viljeonsdrift on the 27th.

During the time that the Unit was at Taibosch Major Crompton, taking with him Sergeant-Major Brown, R.E., and Companys Sergeant-Major Rorke, went south with the field telephones to attempt to make temporary communication at the point where the telegraph lines had been cut by the Boers. Major Crompton returned to his command at Taibosch, leaving the two non-coms. with Lord Kitchener, who arrived at Kopjes on the 9th. They were able to establish communication with the south, and thus kept him in touch to north and south until the telegraph lines were again in working order.

Railhead reached the Vaal River on the 10th of June, and at this point an installation of twelve lamps was erected, and on the 11th the first train crossed into the Transvaal and some supplies were sent to Lord Roberts at Pretoria.

It may be here remarked that as during the advance of railhead from Bethulie to the Vaal the arc lamps were worked on nineteen nights, it is probable that the period of reconstructing the line was shortened by nearly the same

number of days, but even if one night's work is only considered to be equal to two-thirds of a day's work the night work rendered possible by the section must have hastened the advance of railhead by not less than twelve days, and the money value alone of this to the nation must have many times repaid the entire cost of equipping and sending out the Electrical Engineers.

After one night's lighting at the Vaal the very thorough destruction of the line to the south by De Wet necessitated the sending south for a second time both construction trains; the Unit accompanied them, leaving the lighting equipment at Viljeonsdrift under Sergeant Brown.

The construction trains working south were constantly threatened by De Wet, and on the night of the 14th of June both trains were attacked by him, and were summoned to surrender.

As this was the first occasion on which the Electrical Engineers were under fire, perhaps I may be permitted to describe the attack at some length:—

Very early in the morning of the 14th of June the night working party, which consisted chiefly of Royal Engineers and volunteer Royal Engineers, none of them being Electrical Engineers, were at work rebuilding the crib piers of the recently constructed bridge at Leuwspruit; at this time one of the construction trains was drawn up close to the working party, who were at the break in the line, the other train being about half a mile to the north on its way to shunt empty trucks on a siding a mile further north.

The first trouble noticed was the derailing of the leading truck of the northern train. This was caused by a stone having been wedged by the Boers between the main and the guard rails. As soon as the train was pulled up it was fired on by an attacking party which apparently surrounded it. The troops on the train promptly replied, and with good effect, as the Boers drew off after half an hour's firing and concentrated their attack on the other party at the Spruit, but during this sharp attack the vans and coaches of the northern train were riddled by bullets, and those sleeping in them had narrow escapes. The attack coming at first from the south side, the engine driver started to move the engine northwards. The Boers then made a rush on the unarmed working party, who, with one officer and sixty

men were taken prisoners; the remainder, however, escaped, but could not rejoin the party defending the trains.

The Electrical Engineers had formed the day-working party, and having been many hours at work, and consequently very tired, were sound asleep. Those of them who were sleeping outside the trucks, close to the working party, were captured by the Boers before they were able to regain the train. At this time the Boers' firing was very heavy, and three officers, *i.e.*, Lieutenant Micklem, R.E., Lieutenant Bigge, E.E., and Lieutenant Holmes, of the Royal Irish, were seriously wounded. Three sappers were killed, the engine driver and a number of others seriously wounded, and of the native workmen about thirty were killed or wounded. At this time De Wet sent in a messenger summoning the train to surrender as the Boers were greatly superior in force and had guns. No attention was paid to the message, and the remaining troops, who were then under the command of the officers of the Electrical Engineers, took up a position on a ridge of rocks which ran transversely to the train, from which the train could be protected without the men being exposed. This position was held for several hours—in fact, up to daybreak—the firing of the Boers being continuous and severe. On the other hand, the position we occupied was so strong that the Boers were unable to approach the train, and soon after daybreak they withdrew from the attack.

Towards the latter part of the time the Boers were much disconcerted by the shrapnel which was fired over them by two guns placed by Lord Kitchener in a position to the south.

The night was intensely cold and trying to every one; the whole of the defending party were asleep in the trucks when the attack commenced. Although taken at such a serious disadvantage, every man on the train, without distinction, behaved as coolly and quietly as if there were no enemy present.

It was a difficult matter even for old and trained soldiers to free themselves from the crowd of Basutos who formed the native working party, and who cleared out from the train at the commencement of the firing, but, in spite of this, there was no confusion; ammunition was quietly served out, and our men got into such strong positions that it was impossible

FIG. 6.—Scene of Action at Leeuwspruit.

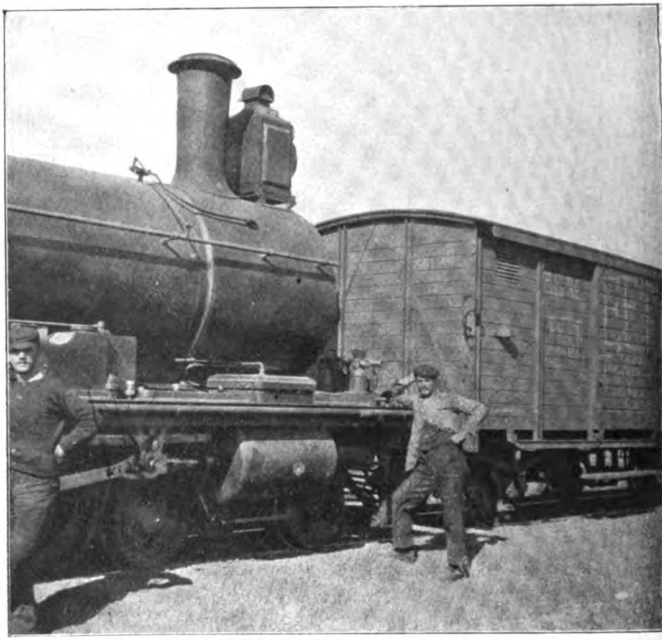
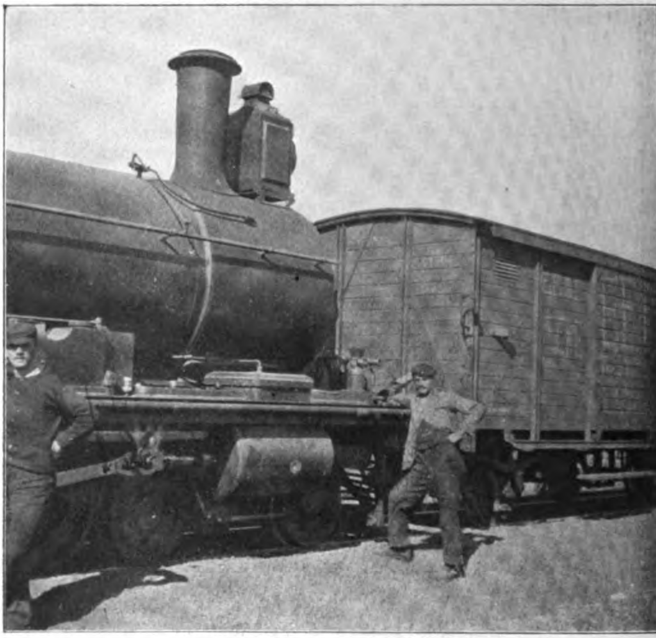


FIG. 7.—Wounded Locomotive.

FIG. 8.—Firing from Van.

FIG. 9.—E. E.-Camp at Pretori .

FIG. 10.—Park of Engines.



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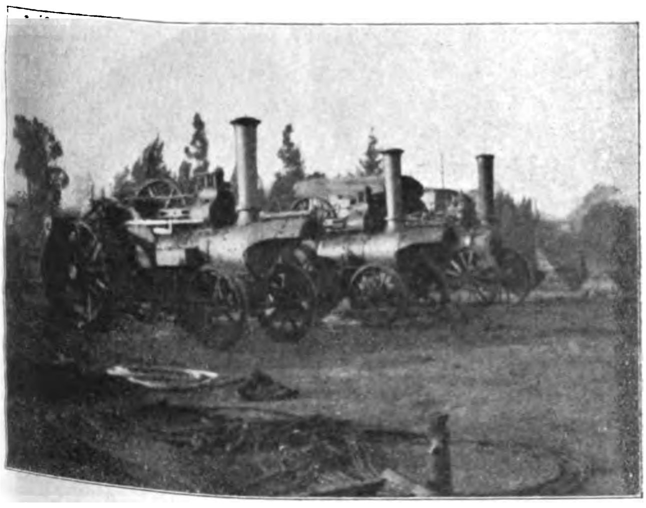

Fig. 10.—Park of Engines.

for the Boers to make their attack successful. Every one behaved so well that it is difficult to single out any one present for special praise. Although the Electrical Engineers engaged on this occasion were comparatively a small party, yet, owing to so many of the night-working party having been surprised and dispersed in the first instance, they formed nearly one-third of the troops left to defend the trains. If De Wet had been successful in catching and destroying these two trains, which contained so much construction material and all the tools, as well as the most skilled body of reconstruction officers, the break in the line of communications would have remained open for a long period, and certainly would have seriously affected the future movements of the more advanced portion of the Army then in the Transvaal.

This attack caused the Electrical Engineers to temporarily lose the services of one officer wounded, and Corporal Sellon and six Sappers taken prisoners. The remainder went south with the construction trains to Rhenoster, and assisted in the building of this important bridge. Whilst there, orders were received from Army Headquarters, that the whole of the Electrical Engineers should come up to Pretoria at once. They started on the 20th, leaving Lieutenant O'Shaughnessy to complete a system of telephones connecting Rhenoster Camp, Leuwspruit, Roodeval, and other points which had been recently threatened or attacked by De Wet. After carrying out this work he joined the headquarters at Pretoria on the 26th of June.

After arriving at Pretoria, the Engineer-in-Chief found quantities of electrical work for the corps, as all the forts which defend the town had been fitted up with various electrical apparatus, not only for electric lighting but there were signal signalling, telephone and other wires, which required to be sorted, labelled, and their uses understood.

The oil engines which supplied the motive power for driving the dynamos had purposely been damaged by the Boers, and had to be repaired and set to work. The small and inefficient searchlights which had been used by the Boers were replaced by a system of incandescent lamps placed so as to illuminate certain points which were liable to be threatened by the enemy during night attacks.

This work at the forts, which was of a very interesting

for the Boers to make their attack successful. Every one behaved so well that it is difficult to single out any one present for special praise. Although the Electrical Engineers engaged on this occasion were comparatively a small party, yet, owing to so many of the night-working party having been surprised and dispersed in the first instance, they formed nearly one-third of the troops left to defend the trains. If De Wet had been successful in catching and destroying these two trains, which contained so much construction material and all the tools, as well as the most skilled body of reconstruction officers, the break in the line of communications would have remained open for a long period, and certainly would have seriously affected the future movements of the more advanced portion of the Army then in the Transvaal.

This attack caused the Electrical Engineers to temporarily lose the services of one officer wounded, and Corporal Sellon and six Sappers taken prisoners. The remainder went south with the construction trains to Rhenoster, and assisted in the building of this important bridge. Whilst there, orders were received from Army Headquarters, that the whole of the Electrical Engineers should come up to Pretoria at once. They started on the 20th, leaving Lieutenant O'Shaughnessy to complete a system of telephones connecting Rhenoster Camp, Leuwspruit, Roodeval, and other points which had been recently threatened or attacked by De Wet. After carrying out this work he joined the headquarters at Pretoria on the 26th of June.

After arriving at Pretoria, the Engineer-in-Chief found quantities of electrical work for the corps, as all the forts which defend the town had been fitted up with various electrical apparatus, not only for electric lighting but there were signal signalling, telephone and other wires, which required to be sorted, labelled, and their uses understood.

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This work at the forts, which was of a very interesting

nature, was followed by teaching the garrisons how to use and maintain the electrical apparatus in working order.

Other parties of our men were employed in fitting up electrical lighting in various public buildings which served as supply stores, and in the large hospitals which were then being started, inside and outside Pretoria. In some cases these new installations were worked from the public supply of the town, in other cases separate generating machinery, *i.e.*, steam engines, dynamos, and systems of conductors had to be put down for each job. The plant for this was made up from material found at or near Pretoria, most of which was in a damaged condition and had to be almost re-made before it could be usefully employed.

During this time, as the whole of the Rand district surrounding Johannesburg is supplied with electric light and power partly from a distant generating centre at Brak Pan, the Military Governor of Johannesburg asked for and obtained the services of Captain Leaf as his electrical adviser, and from time to time various works were supervised by him and by other officers of the Corps, so that the electrical plant of Johannesburg and district was gradually got into order.

It will be interesting to those who have read Rider Haggard's novel, "Jess," to know that the camp at Pretoria was close to the site of Jess's cottage.

Its position was well chosen; a stream of water was handy for washing out the engines and it was close to the railway and railway workshops. Thus, it was in a most convenient position for repairing the various pieces of apparatus that they were installing in the forts and public buildings. Amongst others, the Government Printing Works of Pretoria, worked by their own electric generating plant transmitting power to motors driving each set of printing machinery, was put in order and worked by the Electrical Engineers.

Early in July, Electrical Engineers were several times called upon to extricate an engine which it was proposed to use to haul 12-ton 6-in. quick-firing guns to various positions near Pretoria. This engine and a gun were hauled out of a drift almost in the middle of Pretoria, into which it had sunk in the course of an experimental run.

A few days later, after the driver of this engine had placed

the gun in position near Deerdepoort, he took his engine down to a spruit in order to fill up his water tanks, but approached too closely to the soft ground, so that the engine turned over on its side and could not be got out until we were sent for.

Great praise is due to Captain Lloyd and Captain Leaf and the detachment engaged on this work, which was carried on throughout the night. The way in which the Electrical Engineers handled the engines and gun made it evident to the officer commanding the artillery that the Electrical Engineers were so capable, that he placed the engine and the two guns in their charge, and the subsequent work of placing these, the heaviest guns ever taken into the field, was carried out by the officers and men belonging to the Corps.

On the 24th of July, a 6-in. quick-firing gun, weighing with its carriage 12½ tons, was hauled to the top of Quagga Kop, seven miles to the west of Pretoria, and 1,300 feet above it; the average slope up which the gun was hauled was 1 in 10, but there were point parts of it which were steeper.

On the 1st of August a similar gun was hauled up a slope averaging 1 in 6, and in some places 1 in 5, to a redoubt on the top of this hill, about five miles east of the town. A few days later two large traction engines belonging to the Director of Steam Transport were put under our charge, under the officers of the Electrical Engineers, and with these and the other three engines, making five traction engines, a regular daily service was organised, and stores of every description were transported to various points, chiefly to the westward of Pretoria, the longest run being to Commando Nek, twenty-six miles distant, where a depôt was formed for flying columns. The service on this road lasted for many weeks, in fact, up to the time the Corps started for England, and was carried out without any mishap or loss, although during the whole of the time the line was threatened by the Boers, and we were informed that sniping frequently went on, but as far as we were concerned no one was hit. A new system of escorts was adopted; sufficient men to form two or more escorts being put under the command of the officers of the Corps and encamped with us.

The anxieties connected with this service were greatly reduced by an excellent system of signalling the position of the trains, which was introduced by Captain Lloyd.

Early in June a part of the detachment left at Bloemfontein left under Lieutenant Stubbs and worked under the Army Telegraphs repairing telegraphs and erecting new lines. They trekked the whole journey from Bloemfontein to Pretoria, only arriving at Pretoria towards the end of July. After their arrival at Pretoria Lieutenant Stubbs' party were employed for some time on new telephone lines connecting the forts with the town, and later on took another party down westwards to Standerton.

Towards the latter part of August a party of Electrical Engineers, under Captain Lloyd, were sent up to Brugspruit with a set of searchlight apparatus and accessories, which was erected, and the light shown from the top of the shaft of a colliery near Brugspruit Station, the dynamo being driven from the mine engine. Captain Lloyd returned to Pretoria and left the detachment for some weeks under the command of Lieutenant Bigge, and there is no doubt that the presence of this searchlight greatly reduced the liability of night attacks from a strong commando under Erasmus, which threatened the Pretoria and Delagoa Bay Railway at this point.

On the 4th of September one of the engines, with dynamo and sixteen arc lights, was taken down to Machadodorp by Captain Leaf and a small party of Electrical Engineers, and at this point an installation was erected to supply light to the various running-sheds and loading-stages, as at that time convoys which supplied three columns with food had here to be loaded.

On the 31st of August, Sergt.-Major Brown, R.E., and Corporal Dalton were attached to Lord Kitchener's staff to use their bicycles and field telephones as required at the front.

Up to the time of the arrival at Pretoria, as the officers and sappers were constantly employed on railway work, little opportunity was given for the sappers to use the bicycles, but after arrival at Pretoria they proved to be of the greatest value; for as the work at the forts and buildings was scattered over a large area it necessitated the officers and men moving rapidly from point to point, and

FIG. 11.—"No. 3" Hauling 12-ton Gun.

FIG. 12.—Heliographing for Orders.

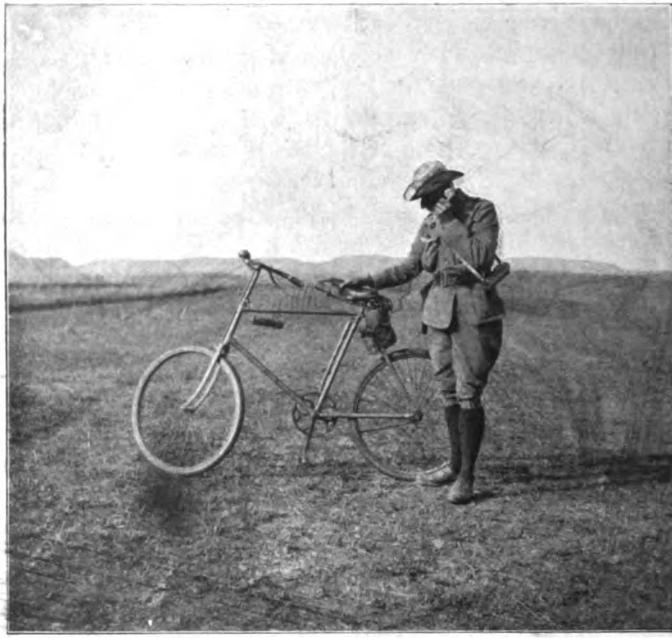


FIG. 13.—Telephone worked on Bicycle.

FIG. 14.—Sapper Melsom with 90 lbs. of Wire on Bicycle.

the whole of the bicycles were in full use, so by their aid the twenty men who rode them were almost doubled in value.

On the 17th of September the writer, accompanied by Captain Leaf, was sent down by Lord Roberts to the low country to the east of Machadodorp, in order to report whether any of the traction engines could be efficiently used there. At this time Captain Bain also came down to Waterfal Onder in charge of the railway telephone work, and Lieut. O'Shaughnessy was in command of the more advanced telegraph work near Koomati Poort.

Early in October the writer was ordered to England by Lord Roberts, in order that his recent experience might be utilised in designing traction engines for military purposes. Captain Lloyd re-assumed command.

From this date the work went on uninterruptedly until the later end of October.

The unit by this time was in a very scattered condition, the large number of jobs being carried out all over the Transvaal and Orange River Colonies demanding small detachments at various places.

It was whilst in charge of his Standerton detachment that Lieutenant Stubbs so nearly lost his life. His duties necessitated a journey by rail on a line known to be threatened by the enemy.

At a point on the line near Vlaklaagte, a few miles north of Standerton, something was observed on the line which looked rather like dynamite.

Lieutenant Stubbs went forward to examine, and was immediately fired on by a large party of Boers concealed about three hundred feet off.

Trying to regain the engine he was hit again and again until at last he rolled into the ditch by the side of the line.

The train was captured and all not killed or wounded were taken prisoners.

The train was then blown up and burnt.

Towards the end of October orders were received from the Engineer-in-chief to concentrate the unit and hand over the majority of the stores so as to be ready to move homewards on receipt of further orders.

The various detachments were gradually collected, and on October 25th, exactly four months after they arrived in Pretoria, the unit steamed south for Bloemfontein.

Seven men were left behind in Pretoria to take their discharge there; four of these had been given civilian employment under the Imperial Military Government, and three were taken up by private employment on the Rand.

A forty-eight hours' journey took them to Bloemfontein, where they completed the handing over of equipment and packing for our final departure.

But even during this time the "handy man" was not allowed to be idle.

Six to eight miles of telephone line connecting outlying camps were laid under Captain Bain's direction, whilst Captain Lloyd was sent off to Norvals Pont to report on an electric-light installation at the hospital there. He also had to report on the future lighting of the railway depôt at Bloemfontein from the new Town Central Station.

Had not orders for the unit to move south finally for Cape Town been received it is probable that the men would still be discovering fresh jobs to turn their hands to.

Yet one more check was met ere the unit finally arrived at Cape Town.

No transport was absolutely ready, and so, to avoid the possibility of the hardened and fierce warrior striking terror into the hearts of the peaceful inhabitants of Cape Town, the bloodthirsty Electrical Engineers were kept for three days in the safe camp of Stellenbosch, and not until Saturday, November 17th, did they reach the port, where the train took them right alongside the *Norham Castle*. After an uneventful and extraordinarily fine passage the ship was brought alongside the quay at Southampton on the evening of the 6th of December.

ADDENDUM.

NAMES OF THE SOUTH AFRICAN DETACHMENT OF ELECTRICAL ENGINEERS (R.E.) VOLUNTEERS.

Returned to England.

Lieut-Colonel R. E. CROMPTON.
Captain F. L. LLOYD, R.E.

Captain A. BAIN.	Captain H. M. LEAF.
Lieutenant J. J. F. O'SHAUGHNESSY.	Lieutenant A. H. POTT.
Second-Lieutenant H. F. BIGGE.	Sec.-Lieut. F. POWELL WILLIAMS.

Sergeant-Major G. A. Brown, R.E.
Company Sergt.-Major E. Rorke.
Sergeant W. S. Entwistle.
Corporal H. H. Bicker-Caarten.
Corporal W. Dalton.
Second-Corporal E. M. Sellon.
Second-Corporal A. I. Hodgson.
Lance-Corporal H. R. Allen.
Lance-Corporal S. W. Melsom.
Lance-Corporal C. F. Love.
Lance-Corporal A. R. Peart.
Sapper F. D. Arundel.
Sapper W. C. Cooke.
Sapper A. J. C. Devonshire.
Sapper G. J. H. Elliott.
Sapper E. C. Horsley.
Sapper A. E. Minns.
Sapper N. W. Pirrie.
Sapper F. G. Payne.
Sapper H. B. Tilley.
Sapper F. J. Wallis.
Sergeant-Inst. C. T. Ruse, R.E.
Sergeant J. H. S. Phillips.
Sergeant A. H. I. Graham.
Corporal A. Charlton.
Corporal W. H. Hossack.
Second-Corporal J. Rook.
Second-Corporal C. Landon.
Lance-Corporal G. Charlton.
Lance-Corporal D. F. Colson.
Lance-Corporal M. N. Crawford.
Lance-Corporal A. O. Wiltshire.
Sapper H. Bertram.
Sapper W. G. Carter.
Sapper R. H. Brander.
Sapper R. W. Holliday.
Sapper L. H. Hounsfield.
Sapper H. A. Paris.
Sapper F. J. Phillips.
Sapper R. B. Roberts.
Sapper J. D. Taylor.
Sapper E. J. Wright.
Sapper F. J. Young.

Accepted Commissions in Royal Field Artillery.

Second-Corporal D. G. W. Hume.
Second-Corporal J. H. Stone.

Remaining in South Africa.

Sergeant T. H. Brown.
Sapper J. M. Bowrey.
Sapper C. W. S. Paine.
Lance-Corporal A. E. Levin.
Sapper H. R. Claxton.
Sapper C. E Silverthorne.
Sapper F. C. Stephens.

Left in Hospital in South Africa; but now returned to England.

Lieutenant J. H. Stubbs.
Lance-Corporal C. R. H. Thorn.

Died in South Africa.

Second-Corporal A. Holdaway (at Bloemfontein).
Sapper E. C. Short (at Kroonstad).
Sapper W. C. Weakley (at Viljoen's Drift).
Sapper E. J. West (at Wynburg).

The President: We are not going to have any criticism on this paper. I think perhaps there has been a little too much criticism in this country of the military operations in South Africa. In addition to that, the only condition on which Colonel Crompton was allowed by the War Office to give us the paper was that it should not be criticised. For

that reason he has called it a lecture, and in calling it a lecture it is evident that he thought he could take liberties. When a man reads a paper he is supposed to read it as it is printed, but Colonel Crompton has added a great deal to the printed matter previously supplied. I very much hope that all the additions he has made will be inserted, as they are most interesting. I think we should also like Colonel Crompton to select a few of the views he has shown us this evening, in order that they may appear in the Journal. There were so many interesting things in the lecture that one does not like to particularise, but I am sure that the Norfolk Regiment, who, the lecturer said, were so easily educated in electrical matters, would value the testimony which Colonel Crompton had given them almost as much as any other testimony they might get during the war, however valuable. Again, without attempting to particularise, I may tell you that I have heard five different accounts of the Leeuwspruit fight from students of mine who were in it. From Colonel Crompton himself I have heard three different accounts, to say nothing of the account I got from Captain Lloyd. The account given in the paper is not like any of the others I have been told—it is too sober; from what I can make out it was the liveliest time on record for all our people. I did not know when I gave that address on Tuesday night what a lot of work had been done by the Electrical Engineer Unit in Africa, and yet I think I said on Tuesday night all I have to say, and I believe that my words voiced the feelings of the Institution. I have to announce that the Council has decided to issue to each member of the Electrical Engineers Unit a copy of that short address[1]

[1] ADDRESS OF PROFESSOR PERRY, AS PRESIDENT OF THE INSTITUTION OF ELECTRICAL ENGINEERS, TO THE SOUTH AFRICAN DETACHMENT OF THE ELECTRICAL ENGINEERS (R.E.) VOLUNTEERS, 18TH DECEMBER, 1900.

"Lieut.-Colonel Crompton, Captain Lloyd, Officers and Men of the Electrical Engineer Unit of the South African Army; in the name of the Institution of Electrical Engineers, I welcome you home.

"When Dr. John Hopkinson suggested that all British Professional men, and particularly Engineers, should prepare themselves in time of Peace for giving their professional services to their Country in time of War, he created the germ of what may become the greatest and best line of defence of the Empire.

on vellum paper, with the seal of the Institution. I will, now ask you to thank Colonel Crompton for his lecture with acclamation.

The vote was carried with acclamation.

Mr. ALEXANDER SIEMENS: I have great pleasure in proposing the following resolution :—

"That the Institution of Electrical Engineers offers the most cordial congratulations to the members of the Corps of Electrical Engineers (Royal Engineers) Volunteers, forming the Electrical Engineer Unit of the South African Army, upon the patriotic devotion that they have shown in placing themselves and their technical skill at the service of their country, and upon the successful termination of their arduous and self-denying labours during nine months of active service in the field."

No words of mine can support this resolution better than the lecture which we have just heard. I want to call attention to the skill which the officers leading the detach-

"You have carried out successfully the very first experiment. We of the Institution know how much you have sacrificed. I speak neither of social pleasures nor of home comforts. I do not speak of the dangers you have risked, either from the chances of war or from that more dreadful enemy, disease. These were common to you and all other Volunteers. But you gave up positions and chances of promotion in your profession, a sacrifice which we of the Institution are particularly well able to appreciate.

"For those who have died we mourn not 'as those without hope': Hope that a life laid down by a man for men is not a life thrown away; Hope for a country that can still breed sons who for her sake are not afraid to die.

"We are assured that in the opinions of the Generals your small Force was of very great service. In particular with the aid of your electric lights the work of mending the broken bridges went on by night as well as by day, thus saving this country millions of money, and who knows how many lives?

"You did any kind of engineering work that had to be done, and showed yourselves the handiest of 'handy men.' Officers and men alike took their full share of actual physical toil; but to us civilians, members of the Institution, the distinction between officers and men is merged in the fact that all alike were worthy representatives of the Electrical Engineering Profession. We stand higher in our own opinion and, as we believe, in that of the world, in that our profession has developed in you that common sense, that resourcefulness in time of trouble, that reserved power and moral courage which have distinguished you particularly in an army of distinguished men."

ments have shown in preserving their men from disease and from attack. In this you will allow me, perhaps, to say I am in a small way an expert, as I went through the same sort of experience thirty years ago, and therefore appreciate perhaps more than any of you the skill and the discipline which are necessary to produce the good results which Colonel Crompton has described to us to-night. It is also perhaps not a criticism of the paper if I add that the action of the Electrical Engineers, and their great utility during the war, has shown that the Volunteers are not such a despicable force as the enemies of volunteer service generally want to make out. Of course I served under conscription, but even then I can add my testimony that the best soldiers were the so-called Volunteers, the well-educated ones, because they did what the Electrical Volunteers have done—they obeyed orders, and did not talk. I have great pleasure in moving this resolution.

Mr. HUGO HIRST: It is indeed a great honour and privilege to be allowed to second Mr. Siemens' words of appreciation of the deeds of the Electrical Engineer Volunteers. May I add, at the request and with the permission of the President, a few words that suggest themselves to me on this occasion. At the beginning of this war we all thought the overwhelming weight of this Empire might quickly crush resistance out of what we considered to be two small countries; but we found that we were sadly misled. The unpreparedness under which we started this war, and which, as Sir Wilfrid Laurier said, redounds to the eternal glory of this country, brought us into unpleasant and unexpected difficulties. These, however, gave us electrical engineers a chance of showing what an intelligent organisation could do. Our corps was only an adjunct to an adjunct of the Army, yet they did the wonders of which Colonel Crompton has told us here to-night. When this war is finished, we shall have to start that bigger fight—not a fight against little countries, but a battle for the industrial supremacy of this country against an array of big nations. In this battle electrical engineers will not be an adjunct only: I think they will be looked upon as the leaders of the nation. It will be they who will be the general staff, who have to form the plans and the tactics for the nation, and they will have to find the ways and means of

communication, and will have to provision hundreds of millions of men. To do this the members of this Institution have a great duty to perform, and much work to do. We want to learn in this work from what we have heard to-night. I think men that have done what our Electrical Engineer Volunteers have done, who have risen to the emergency of the occasion in the manner we have heard, who have shown that they are willing to sacrifice everything to their patriotism, and have disproved that they have gone out to South Africa merely for the sake of a rough life, or for fighting, for a bullet or a medal, who have gone through all the hard drudgery of an engineer's work in a campaign, are fit to do any work. I think those men should be singled out, should be hall-marked, if I may put it in that way, for the rest of their lives for all the important positions that the work in which we are engaged may bring forth. I think it is the duty of every member of this Institution who is an employer to remember at all times the sterling qualities, the hard work, the perseverance, and the high sense of duty of this corps. It is our duty to help them to get those posts of honour and those remunerative positions, not only for what they have done, but also for the glory and the prestige that they have shed on this Institution. With these words I have much pleasure in seconding Mr. Siemens' proposal.

The PRESIDENT: Before putting the resolution to the meeting, I should like to say that that suggestion of Mr. Hirst's that the members of this Institution who are employers, and are in a position to do it, ought to remember that some members of the corps may be out of employment.

The resolution was put, and carried with acclamation.

Mr. J. W. SWAN: Colonel Crompton has made us realise that war has its bright as well as its sombre aspects; indeed, the lights of the picture he has presented to us so vividly to-night have almost overpowered the shadows of the picture. And, gentlemen, there are shadows that I think we must not overlook. We lately rejoiced in the return of a very large proportion of the men who went out to render their help in the defence of the honour of the nation, and in the protection of the lives and liberty of our kindred in South Africa. We rejoice that such a large proportion of those men who went out nine months ago have returned—returned safe and well, most of them

looking even better than they looked when they went away. But, gentlemen, not all the sixty-four men who went away have returned. All of those who went, no doubt, realised the perils that the occasion might place them in, and were prepared to meet the worst consequences, but only four had to make the sacrifice which they were all ready to make, to render up their lives in the service of their country. The names of these four men, honoured names—names, I trust, that will never be forgotten—are Second Corporal A. Holdaway, Sapper E. C. Short, Sapper W. C. Weakley, and Sapper E. J. West. "These few, these happy few," will never return. The manner of their death was pathetic rather than dramatic. It was not their fate to fall amidst the din and fury of battle, but their death was none the less heroic in that they died a lingering death in the hospital, stricken down at the post of duty not by Mauser bullets sped by the hand of an unseen foe, but by the deadlier stroke of that subtlest of enemies, that with sleuth-hound tenacity dogs the footsteps of armies in the field—enteric fever. Just as surely as the bullet sends the sorely wounded man to the hospital, so with equal sureness this lurking enemy strikes home, and exacts the same endurance of long-drawn-out suffering, and with even greater likelihood that all the skill of the doctor and all the care of the nurse may prove of no avail, and that the end of all is—a few freshly-turned sods on the veldt. But no, that is not all, for it is not true that death is the end of life: life and the deeds of life are ineffaceable. These few gallant members of a gallant band have the supreme honour of having died serving their country in a good cause. So dying, they have achieved immortality. They fell marching in the path of duty, and now, as ever, "The path of duty is the way to glory."

Let us always remember them, and let us also remember those to whom they were near and dear, and let us try to lift, if ever so slightly, the burden of their sorrow, by our sympathy. I beg to move, "That the Institution of Electrical Engineers desires to express its deep sorrow, and to tender its heartfelt sympathy to the relatives of Corporal A. Holdaway and Sappers E. C. Short, W. C. Weakly, and E. J. West, who lost their lives while serving in the Corps of Electrical Engineers (Royal Engineers) Volunteers in South

Africa, and so gallantly devoting their technical skill to their country's need."

Sir HENRY MANCE: It has occurred to me that although there are many who would have seconded this resolution with greater eloquence, there is a certain fitness in asking me to perform the duty. I suppose I am the oldest Volunteer in the Institution of Electrical Engineers. I joined the movement in the fifties, and for many years before I left India I was an officer in the Volunteers there. There is another reason why I feel great sympathy with this evening's proceedings, namely, because I have two sons in South Africa, one of them an officer of the Royal Engineers, who was, I believe, on board the first train which entered Mafeking after the siege. I think that this resolution will be some consolation to the relatives of those who have lost their lives. I remember some time ago being at Southampton and witnessing the departure of some thousands of our troops, as happy as men could be. Among them were many men who were making great sacrifices, but when I walked away, with a rather heavy heart, I felt that those who were making the greatest sacrifices were the wives and mothers and the women of this country.

I beg to second the resolution.

The PRESIDENT: With Mr. Swan's permission, I should like to add one line to the resolution, namely, "and that the Secretary be instructed to communicate with their relatives."

The resolution, with the addition proposed by the President, was carried in silence, all the members present rising in their places.

The PRESIDENT announced that the scrutineers reported the following candidates to have been elected :—

Associate Members:
Eric Philip Barfield.
Charles Shore.

Student:
George Thomas Lundy.

MANCHESTER LOCAL SECTION.

Paper read at Meeting of Section, November 27th, 1900.

RELATIVE ADVANTAGES OF DIRECT-CURRENT AND THREE-PHASE DISTRIBUTION FOR SMALL INSTALLATIONS.

By HARDMAN A. EARLE, Member.

When accepting an invitation to read a paper before this Institution, I was for some time in doubt as to what subject I should choose; none was particularly uppermost in my mind as one upon which I wished to discourse, but I came to a decision while travelling abroad; the question covered by the title of my paper being brought most prominently before me, owing to the competition and different statements I met with, with regard to the relative advantages of three-phase and direct-current machinery for small and medium-sized installations. Owing to this, it occurred to me that a comparison between the two systems would be of interest and likely to give rise during its discussion to points which would be a guide for the future. Competition is not always, especially in some countries, carried on on strictly commercial lines, and I have experienced instances where a competing firm, finding it could not secure an order for direct-current machinery, has offered polyphase machinery as an alternative, singing its praises at great length, setting forth advantages without number, and naturally ignoring the other side of the question; this is not as it should be, but with inexperienced purchasers, with no one to guide them, it is at times successful.

I have found the title I first adopted for my paper somewhat too limited in its scope, and have briefly considered questions which relate to the distribution from substations, as well as that of the choice of machinery and distribution for small installations.

The type of machinery and the system to be adopted for supply and distribution are, in the case of large plants, most carefully considered; simplicity of design, first cost, and subsequent economy being among the most important of the many factors.

In the case of small installations, however, such as are put down to supply light and power for mills and factories, the question is not infrequently decided irrespective of theoretical considerations.

The purchaser in England is very usually in the hands of the consulting engineer, but in countries where this commodity does not exist he is often guided by the persuasive power of the seller, and sometimes by fashion. For the lowest price may mean but little as regards cheapness when there is no specification. There are many ways of preparing a low tender; and the omission of something in one which is included in another, the adoption of different voltages, various groupings of lamps and motors, different speeds for generators and motors, may give one system an apparent advantage over another which it does not in reality possess.

Many firms have, up to the present, given their chief attention to direct-current work, and this has met the wants of the smaller installations as well as those of the greater portion of the large central stations. Single-phase supply at high voltage, with distribution from transformer stations, has competed keenly with direct current, but lamps of higher voltage, together with three-wire distribution, has given the latter a long lease of life, and has enabled it to be employed for large areas without undue loss or a prohibitive cost of copper.

We have seen 50-volt and subsequently 100-volt lamps in regular use for large installations, but now 200 up to 230-volt lamps are quite the accepted standard, and this higher pressure has so largely reduced the first cost of copper that in many stations where the use of alternating currents was formerly warranted, direct-current machinery is being put down, and even in some instances the alternating-current machinery being taken out. Running and driven balancers, together with feeder boosters, are required as auxiliary machines for direct-current three-wire distribution, from substations dealing with large powers, and feeding over a considerable area; but it is more than probable that in the future 400-volt lamps will be available, which, with a two-wire distribution, would render the two first-named machines unnecessary, and eliminate the cost of the centre wire. As polyphase and monophase machinery lives on the price of

copper, it can be fairly assumed that every saving in this respect will take away their livelihood and reduce their utility. Where lighting constitutes the largest proportion of the load, the copper required is proportional to the watts per candle taken by the incandescent lamps, any reduction, therefore, in this respect is of great importance; lamps are, I understand, shortly to be put on the market consuming 2 watts per candle, or even less, and every advance in this direction is, I again hold, to the advantage of direct current, and will enable it to cover a wider field, for who will use high voltages and transform down, if they can use low with equal economy, or include complications when they may be omitted? All auxiliary machinery and apparatus has only one object, and that is to reduce the price of the mains, or, as I have seen it stated, adopted in the vain endeavour to cheat Ohm's law out of its due tribute of copper.

There are some who blindly champion alternating and polyphase systems, call commutators excrescences, and quote experiments which claim to show that polyphase weigh a mere fraction of direct-current machines. A statement in Herr von Dobrowolsky's remarks in the discussion on a paper read by Herr Görges in 1892 was quoted in the first edition of a book, and has again appeared in the second edition, namely, that a certain multipolar continuous-current machine gave 11,000 watts, but that when a three-phase armature was run in the same fields, it gave an output of 33,000 watts. I doubt this test being one which one could consider upon a commercial basis. On turning, however, to the paper in question, I find that Herr von Dobrowolsky also said: An alternating-current machine is so totally different in its construction to a direct-current machine, that such comparisons cannot be fairly made, and that it is equivalent to saying that a spoon has an efficiency of 100 per cent. when used for soup, but only one of 50 per cent. when used for cutting.

Notwithstanding all this, the polyphase system is at the present time the most satisfactory solution of long-distance transmission, and will be utilised more and more to transmit large powers into the centre of towns, and to cope with the many difficulties which present themselves; but the chief point I desire to raise is, whether the distribution from the substations should be by polyphase or direct current, and

whether for smaller installations one system offers such advantages over the other as to warrant a preference being given.

Notwithstanding the existence of several eminent advocates of single-phase machinery, I do not propose to consider it, nor have I had to deal with it in connection with the competition I have experienced, especially abroad.

With regard to the two remaining rival systems, the commutator seems to be the red flag of polyphase exponents, but any trouble that has been experienced on this behalf is merely a passing nightmare, and has only occurred with machines of large power running at high speeds, in connection with which considerable experience is required and very high class workmanship demanded in order to enable carbon brushes to maintain good contact on a surface running sometimes as high as 40 miles an hour; this difficulty has been experienced by most of us, but is being rapidly overcome, and in a short period it will be a thing of the past. It is, however, much to be desired that the high engine speeds which have been saddled upon us for plants of 1,000 horse and upwards may in the future be reduced some 20 per cent.

With reference to the comparative weights of direct-current and polyphase generators, we may take as a good example of the latter one of the 32-pole three-phase generators built for the Central London Railway, and which has an output on full load of 850 kw. at 94 revolutions; this machine has a weight of 37 tons, or, with exciter, say 39 tons. As an example of a large direct-current traction and lighting generator, we may take one of a number of 10-pole machines now being built at Salford Ironworks, having an output of 900 kw. with fixed lead, and running at 95 revolutions per minute. This machine has a weight of 45 tons, or, correcting for the increased output, it equals 42 tons; this machine could, however, have been built lighter as a shunt generator, with the compound windings omitted, and, with the smaller range of voltage then necessary, the magnets would have been lighter, and, probably with advantage, more in number; the weight would then have been practically identical with the polyphase generator, with which it has been compared.

With regard to the weights and prices of still larger

generators, I have compared a 1,400 kw. × cos ϕ polyphase generator running at 93 revolutions with a direct-current one of the same output, and, for the same speed, the former, with exciter, would weigh approximately some 64 tons, and the direct-current generator approximately the same. Comparing the prices of the above machines, the polyphase has the advantage and is approximately some 12 per cent. cheaper to build, this being chiefly due to the cost of the commutator on the direct-current machine.

There is, however, one point which cannot be passed by unnoticed, and that is the small safety clause attached to the output of the polyphase machine, namely, cosine ϕ—what is this? Why it means that on an inductive load this apparent 12 per cent. advantage is wiped out, and may even, and very probably will, put the boot on the other foot; but more of this later on.

With regard to smaller sizes of 200 to 400 kw., I do not find that there is much difference; in fact, the figures I have tend to show that the advantage is on the side of direct current, but I will not press this point.

Respecting the weights of the two types of motors, the polyphase type with squirrel-cage rotor is considerably lighter, but the large motors of 50 to 100 horse-power with wound rotors weigh about the same.

Comparing the price at which the smaller sizes are sold, the polyphase have an advantage of about 5 per cent.; but figures I have carefully examined for motors from 10 to 100 horse-power with wound rotors show a good average of 10 per cent. in favour of continuous current, when compared with polyphase motors imported into this country, and the cost of importation does not amount to 10 per cent.

Considering next the cost or weight of mains, the advantage is on the side of three-wire direct-current distribution, as may be seen from the following table on pages 314 and 315.

In that table it is assumed that the various systems are for incandescent lighting as well as for power, and that the voltage is limited by the lamps, the circuits being so arranged that each lamp can be switched on singly.

As regards the voltage, column 1 gives the virtual volts between any two wires when lamps of the same pressure, namely 200 volts, are employed on each system; but this

figure may certainly be taken exception to in the case of the alternating systems, for it must not be forgotten that their maximum voltage is the $\sqrt{2}$ times their working voltage, or 1·41 times as great. And this cannot be lost sight of when taking into consideration the questions of insulation and risk from shocks. I have, accordingly, given in column 2 the maximum voltage between any two mains on this basis.

There is also another point to be borne in mind in connection with the mains for polyphase systems which contain many motors, and that is for equal loss they must be increased in section at least 10 per cent. above that given in the table, and required for continuous-current systems, in order to allow for the loss due to wattless currents, and this figure may have to be still further increased to 20 per cent. or even more should many of the motors be put down to deal with very variable loads; in fact, the section of the mains in the table must be increased in the inverse ratio of the power-factor of the system, taking into consideration both motors and lamps.

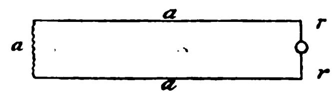
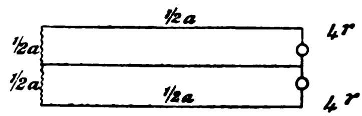
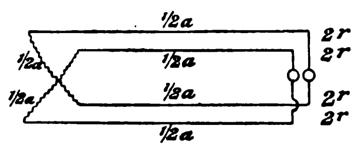
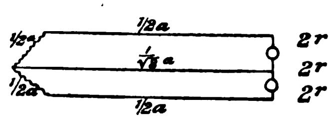
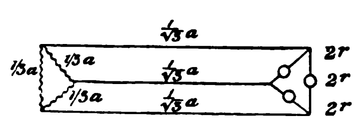
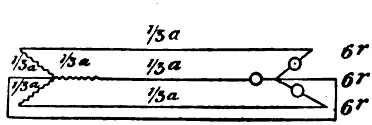
In the comparison, a third or common wire has been included, where necessary, to fulfil the condition of individual control, but the systems are assumed to be in balance, *i.e.*, there is no loss in the centre wire, which has been taken in all cases as 25 per cent. of the weight of an outer.

It is seen that continuous-current three-wire systems are only beaten by 1, namely, in the case of the three-phase star with common return, but then the saving by having only three wires instead of four to fix and insulate would cancel this small difference, not to mention the better regulation which can be obtained with continuous-current machinery.

With regard to this small difference of 1, the three-phase star has, moreover, no right to, for it is entirely eliminated, and the tables are turned, by what I have said respecting the loss due to wattless currents when motors are used; and the three-wire direct-current system is then found to be at least 10 per cent. the best of all, as regards the weight of copper.

From the way I have drawn the diagrams of the three-phase star circuits, it can readily be seen why, when lamps are used, the fourth or common wire is necessary to maintain proper regulation of voltage on the lamps, for without it

EQUAL PRESSURE ON THE LAMPS. EQUAL POWER

System.	DIAGRAM OF SYSTEM. represents Dynamo windings „ 200-Volt Lamps.	Virtual Volts between any two wires = V.	Maximum Voltage.
Continuous Current 2 wires		200	200
Continuous Current 3 wires		400	400
2-phase 4 wires		200	$V\sqrt{2}$ 283
2-phase 3 wires		$200\sqrt{2}$ 283	$V\sqrt{2}$ 400
3-phase mesh		200	$V\sqrt{2}$ 283
3-phase star		$200\sqrt{3}$ 346	$V\sqrt{2}$ 490

TRANSMITTED. EQUAL LOSS IN THE LINE.

Current in outers for equal total power = $2\,00a$.	Resistance of each outer for equal total Loss = $2a^2r$.	Weight of each outer. — No current in centre wire.	Weight of the centre wire taken as $\frac{1}{2}$ of each outer.	Total copper for equal lamp pressure power and loss.	Weight of Copper cc. = 100.
a	r	1	—	2	100
$\frac{1}{2}a$	$4r$	$\frac{1}{4}$	$\frac{1}{16}$	$\frac{9}{16}$	28
$\frac{1}{2}a$	$2r$	$\frac{1}{2}$	—	2	100
$\frac{1}{2}a$	$2r$	$\frac{1}{2}$	$\frac{1}{2}$ same as outer	$1\frac{1}{2}$	75
$\frac{1}{\sqrt{3}}a$	$2r$	$\frac{1}{2}$	—	$1\frac{1}{2}$	75
$\frac{1}{3}a$	$6r$	$\frac{1}{6}$	$\frac{1}{24}$	$\frac{13}{24}$	27

the system would be comparable to a continuous-current two-wire system with three lamps in series.

Turning next to the question of running motors upon the circuits, the points to be considered are—

(1) Starting Torque. (3) Constancy of Speed.
(2) Regulation of speed. (4) Efficiency.

Polyphase motors are essentially constant-speed machines, and the speed of the smaller sizes is high, the arrangement of the winding is limited, and in this respect they do not so readily lend themselves, as continuous-current motors do, to windings by which any desired speed can be obtained. Various ingenious methods have been adopted to meet the requirements, which are more or less satisfactory, but there is still considerable room for further development.

1. Starting Torque.

A continuous-current motor, even when shunt wound, exerts its full torque, with a small increase of current over the full load current, and is capable of satisfactorily dealing with any work for which it may be employed; small three-phase motors with squirrel-cage rotors, starting with full torque require a momentary rush of current, approximately equal to 2½ times the full-load current; this is an undesirable feature, and to obviate it motors of larger powers are started up with a resistance in the rotor circuit. This minimises but does not remove the defect.

This behaviour would prevent a three-phase power installation being arranged so that all motors may start up with the generator. With respect to this, I arranged a power installation of 850 E.H.P. in a large spinning and weaving mill abroad, in which are included some ten compound wound continuous-current motors, placed long distances apart, and ranging from 220 to 30 horse-power; in this installation all the motors can start up simultaneously with their generator, on practically full load, the starting current required being not more than some 50 per cent. in excess of the full working current.

In cases where the running torque is constant, but where a great starting torque is required, series wound continuous-current motors offer the best solution.

I have one case especially in my mind, in connection

with a polyphase installation in a cotton mill, where a large number of motors of 8 B.H.P., with squirrel-cage rotors, were put down, each to run a line shaft driving 24 narrow looms; in this case trouble was experienced in starting up, belts coming off, or the motors, expecially on Monday morning, when everything was stiff, refusing to start at all. Larger motors were in some instances put in, and in others fast and loose pulleys were added: a 7-H.P. direct-current motor would have done the same work, and have given better results.

One method of increasing the torque of polyphase motors, on starting, is to increase the voltage on the stator by means of a booster transformer.

Another method is to alter the connections of the stator windings from star to mesh; thus increasing the pressure in the ratio of 1·73 : 1. Another arrangement is to change the connections of the stator coils from series to two sets in parallel.

The requisite starting torque can, however, be obtained from a direct-current motor, whether shunt or series wound, without any of these devices.

2. Speed Regulation.

The regulation of speed, either of continuous-current or of polyphase induction motors, is effected by somewhat similar means.

The speed of an ordinary shunt-motor can be varied in three ways, either by inserting a resistance in the armature circuit, by altering the voltage of supply, or by varying the strength of the fields.

Like shunt or series direct-current motors, polyphase motors, except the smallest sizes, require a resistance to be inserted in the rotor or revolving windings to keep the starting current within bounds. Merely by the use of such a resistance any desired variation of speed can be obtained with either type. With this method of regulation, however, the input remains practically constant, and it is therefore too wasteful to be adopted where a high average efficiency is imperative throughout the whole range of speeds.

A direct-current motor running on a three-wire system with two voltages available, combined with regulation of the field, can be made to yield a very high mean efficiency

equalling 83 per cent. for the whole of the working range—that is for some 66 per cent. of the speeds and an average of 75 per cent. throughout the whole range. Weakening the field by introducing resistance into the stator circuit of a polyphase motor increases the slip and the motor runs slower; but as the field supplies the rotor current in the same manner as the primary of a transformer supplies the secondary, the torque falls off very rapidly.

By doubling the number of poles in the stator winding the speed can be halved; this necessitates, however, an inconvenient number of windings, increases the complication of the switch, etc., and is rather impracticable.

Considering the various devices as a whole, one cannot but be drawn to the conclusion that the direct-current motor on a three-wire system, with two voltages available, or on a two-wire system with double wound armature, together with the provision for some field regulation, is the simplest and most desirable, for it gives all variations of speed most economically, and it can be easily arranged so that there is no jump whatever between one speed and another. Three or four instances have come to my notice where power has been transmitted to a works from a considerable distance by polyphase current, but in connection with which motor generators have been added to supply direct current to motors requiring to be operated through a large range of speed at a high mean efficiency.

3. Constancy of Speed under Varying Loads.

In this respect a shunt wound continuous-current motor acknowledges no superiority to the polyphase; the slip on the latter increases with the load, but shunt wound motors are available which can maintain constant speed from no load to full load.

For Tramway work a polyphase motor will maintain a more constant speed when climbing hills than a series wound continuous-current motor, but as this is at the expense of current, a high speed on the level and a slower speed on hills seems more to be desired, and likely to reduce the maximum current demanded from the station.

4. Efficiency.

I have compared the efficiencies of direct-current motors

which have been most accurately tested, with figures which I consider are fairly representative of what can be obtained with polyphase, and give the comparisons below :—

	3½	6	10	25	50	100 B.H.P.
Direct current	82%	85%	86%	91%	92%	92%
Polyphase	75%	80%	84%	88%	90%	91%

This shows a large superiority for direct-current motors of small power, and a small advantage on the larger sizes.

The power-factor of polyphase motors, as far as any published figures go, as well as those which are obtained from various makers, vary more widely than seems at all necessary, and in order to obtain a fair average, I dotted all the power-factors I could get upon a sheet of paper, and then drew a curve through the lot, and I give you below the readings which resulted from this curve.

Power-factor for polyphase motors on full load :—

B.H.P.	5	10	15	25	50	100
	·76	·79	·81	·83	·86	·88

With regard to the above, it is needless to remark that the power-factor of continuous-current motors is unity.

Having considered how the various operations are effected for changing either the speed or torque or both, let us consider the conditions under which motors have to work ; these may be divided under four heads and stated as follows :—

(1) Constant speed with constant torque.
(2) „ „ variable „
(3) Variable „ constant „
(4) „ „ variable „

Constant Speed with Constant Torque.

This condition is one which exists, when motors are used to drive lengths of shafting, from which again are driven a considerable number of small machines, such as are found in a cotton mill, or a large machine shop ; in this instance the load is fairly constant, possibly not varying more than some 10 per cent. ; it is in such cases that a polyphase motor is at its best, and endeavours to rival the shunt wound direct-

current motor, which, however, is just as good for the purpose.

Constant Speed with Variable Torque.

This second condition occurs in cases where large portions of the load are being frequently thrown on and off; the shunt wound motor is all that can be desired as regards speed on such work, and the current taken is in fair proportion to the load. The polyphase motor is also satisfactory as regards speed, but the current is high on the lighter loads; a considerable percentage is certainly wattless current, but it adds up the C^2R losses, and at the same time decreases the capability of the generator for useful work, and this is a point which must be borne in mind when comparing a polyphase generator with a direct-current one.

We have seen how a power-factor less than unity for the motors necessitates an increase in the size of the mains, and this acts in a similar manner upon the generator. If the current were in phase with the E.M.F.: that is, if the power-factor were 1, in place of averaging, say, ·85, the polyphase generator could do $17\frac{1}{2}$ per cent. more work than it would be able to do under the latter condition. But, again, with many motors working on a system, a power-factor of ·85 cannot always be relied upon, and one of ·75 or even lower may have to be reckoned with. We see from this that the first cost of an installation may be considerably increased by this consideration, and, besides this, the wattless currents exercise a very bad effect on the regulation of a three-phase machine, very much more so than if the currents were in phase, necessitating very much heavier windings on the magnets to deal with a low power-factor than a high one.

Variable Speed with Constant Torque.

This third condition is met with very frequently, for instance, when driving callenders, paper-making machinery, and in pumping, etc. To meet it with polyphase motors the regulating switches are more complicated, and to effect many changes of speed the groupings of the windings become many in number and efficiency is sacrificed; in this respect the continuous-current motor is more easily managed and will yield a higher mean efficiency.

Variable Speed with Variable Torque.

The fourth condition is especially present when driving calico printing machinery; an eight-colour machine, for instance, may be utilised for printing any desired number of the eight colours; the torque increasing practically in direct proportion to the number of rollers in use, the speed of printing the goods at the same time varies in accordance with the number of colours being printed, and with the class of work the machine is doing.

For this class of work a very even turning moment is necessary; one must be able to run up to any desired speed without jumps or jerks, and the contemplation of a three-phase motor arranged for high efficiency at all speeds and to comply with the requisite conditions, is not a taking one.

I have heard the point raised that for factories where there is much inflammable dust about, a chance spark from the commutator might set the place on fire; but perfectly satisfactory entirely closed direct-current motors are at work, not considering the thousands on tramcars, and in factories of all descriptions. Fire-proof gauze covers are also employed for motors; these do not exclude all ventilation, and render the motor quite reliable even where spirit vapours are present.

The facility for the use of batteries on direct-current systems is one which must receive careful consideration. These are continually improving in quality, give excellent results in the hands of those that understand them, and offer great advantages, both as a stand-by and as regulators; they can therefore frequently be utilised to assist direct-current supply, and at times to effect considerable economy, whereas a three-phase battery has yet to be invented.

Polyphase motors appear specially suitable for long lines of railway where considerable distances are travelled without a stop, at a uniform rate of speed, and where crossing points, which would complicate the conductors, do not exist, for beyond a comparatively limited distance high voltage must be used, and then, whichever system is employed, transforming apparatus is necessary; in such instances polyphase supply, with polyphase motors on the train, would not call for rotating transformers, stationary transformers along the line being the simplest and cheapest arrangement.

Such a system is, however, unsuitable for use in towns, with frequent stops and a very variable rate of speed; besides this, I am sure that it would create a great commotion among the inhabitants of a town not 100 miles away, if it were proposed to erect two trolley wires in place of the one, which to some already appears distasteful. Judging from what some of the larger firms on the Continent are doing with respect to polyphase machinery, I understand that although they have given it the very greatest attention, they find that the volume of their direct-current work exceeds that of the polyphase.

I have endeavoured to consider the chief points which should guide us in the choice of a system for use for the smaller installations.

In cases where lighting alone is required, the first cost of polyphase or direct-current would appear to be very similar. The simplicity of the latter system, both as regards the wiring and the regulation of the voltage, to my mind, gives direct current the preference.

Where a number of motors are on the circuit, for whatever purpose they may be required, and whether the system includes lighting or not, I consider that direct current shows a very decided advantage except in a few special cases; moreover, the use of batteries is all but excluded with polyphase systems, even for a night load, and this is frequently of considerable importance. I have, doubtless, to some minds left unsaid many things I ought to have said, and to others said many things I ought not to have said, but this may be more an advantage than otherwise, for it will admit of those shortcomings being criticised during the discussion, and may enable me to fill the gaps and correct my errors.

Mr Miller. Mr. THOS. L. MILLER agreed with Mr. Earle in his conclusions as to the advantages direct-current possesses over polyphase transmission for small installations, and particularly where speed regulation of the machines was a matter of importance. Polyphase transmission had undoubtedly come very much to the front of recent years; but while the system had very considerable advantages where energy was transmitted over considerable distances, where the flexibility of the system could be utilised to the utmost, he thought that for small installations direct-current transmission had, in the majority of cases, decided advantages over it. As Mr. Earle had pointed out, in this matter—as in so many others that could be instanced—fashion, and that idea so

prevalent in some quarters that nothing good—electrically—could be produced in this country, had had much to do with the spread of polyphase transmission over comparatively short distances in these parts. Much was being said at the present time about the spread of polyphase transmission abroad; but the speaker thought that in many cases the conditions under which this work was being, or had been, carried out had been entirely lost sight of. A study of the published records of the work carried out on this system, both on the Continent and in America, showed that in the majority of instances either cheap power or transmission over comparatively long distances, or both combined, had been the chief factors in determining its adoption. Mr. Miller.

Mr. Earle's table giving the weight of copper used in the various systems was very interesting; but in the majority of cases of electrical transmission in small installations the speaker did not think that the weight of copper used in conductors had much influence in determining the system to be adopted. Where no great speed variation was required he was of opinion that, for small installations, a simple two-wire direct-current system had much to recommend it, one of the chief advantages being that it could be put in charge of any ordinary mechanic.

With regard to the larger question of electrical distribution in cities, touched upon by Mr. Earle, he (Mr. Miller) did not think any general statement of opinion could be given, as so much depended upon the special circumstances of each particular case—and until these were known it was better to suspend judgment; but for small installations for factories, mills, and works, he cordially agreed with Mr. Earle in his conclusions as to the advantages of direct-current transmission.

Mr. W. B. Sayers spoke of the great value of a delicate speed adjustment, with practically no loss of efficiency, such as was possible with shunt-regulated direct-current motors when applied to machine tool driving. He pointed out that production could be materially increased by a careful use of this property of the direct-current motor. He instanced a case in which Messrs. Ganz & Co. had been obliged to instal two generators with different periodicities, and, by means of a change-over switch, arrange for any motor to have either periodicity applied to it, with a consequent variation of speed. Mr. Sayers.

Mr. A. P. Wood referred to the drop of pressure which he had observed take place in the supply circuit when a 10-H.P. polyphase motor was switched on to a 100-kw. generator. He had measured it—110 volts down to 70 volts. He then referred to the microscopic clearance in polyphase motors, and said that sooner or later failure must result therefrom—especially in dusty places. Mr. Wood.

Mr. Lindley said that the multiphase motor appeared to him to be an ideally perfect machine from a mechanical point of view. It was all very well to say that commutators did not give trouble. He was a user of direct-current motors, and the trouble was very considerable. He had many makes in his works. Mr. Lindley.

Mr. A. Whalley regretted that judgment against polyphase motors appeared likely to go by default at this meeting because none of the Mr. Whalley.

Such a system is, however, unsuitable for use in towns, with frequent stops and a very variable rate of speed; besides this, I am sure that it would create a great commotion among the inhabitants of a town not 100 miles away, if it were proposed to erect two trolley wires in place of the one, which to some already appears distasteful. Judging from what some of the larger firms on the Continent are doing with respect to polyphase machinery, I understand that although they have given it the very greatest attention, they find that the volume of their direct-current work exceeds that of the polyphase.

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Mr. Earle's table giving the weight of copper used in the various systems was very interesting; but in the majority of cases of electrical transmission in small installations the speaker did not think that the weight of copper used in conductors had much influence in determining the system to be adopted. Where no great speed variation was required he was of opinion that, for small installations, a simple two-wire direct-current system had much to recommend it, one of the chief advantages being that it could be put in charge of any ordinary mechanic.

With regard to the larger question of electrical distribution in cities, touched upon by Mr. Earle, he (Mr. Miller) did not think any general statement of opinion could be given, as so much depended upon the special circumstances of each particular case—and until these were known it was better to suspend judgment; but for small installations for factories, mills, and works, he cordially agreed with Mr. Earle in his conclusions as to the advantages of direct-current transmission.

Mr. W. B. Sayers spoke of the great value of a delicate speed adjustment, with practically no loss of efficiency, such as was possible with shunt-regulated direct-current motors when applied to machine tool driving. He pointed out that production could be materially increased by a careful use of this property of the direct-current motor. He instanced a case in which Messrs. Ganz & Co. had been obliged to instal two generators with different periodicities, and, by means of a change-over switch, arrange for any motor to have either periodicity applied to it, with a consequent variation of speed. Mr Sayers

Mr. A. P. Wood referred to the drop of pressure which he had observed take place in the supply circuit when a 10-H.P. polyphase motor was switched on to a 100-kw. generator. He had measured it—110 volts down to 70 volts. He then referred to the microscopic clearance in polyphase motors, and said that sooner or later failure must result therefrom—especially in dusty places. Mr. Wood.

Mr. Lindley said that the multiphase motor appeared to him to be an ideally perfect machine from a mechanical point of view. It was all very well to say that commutators did not give trouble. He was a user of direct-current motors, and the trouble was very considerable. He had many makes in his works. Mr. Lindley.

Mr. A. Whalley regretted that judgment against polyphase motors appeared likely to go by default at this meeting because none of the Mr. Whalley.

Mr. Whalley.

few experts in this country were able to be present. So far the discussion had ignored the chief assumption of the paper, that power would be generated and transformed at substations by some polyphase apparatus, which meant that if direct-current motors were adopted, rotary converters were needed in the substations and, in addition, a low-tension network. The conditions which would warrant the adoption of polyphase motors in order to avoid the expense of a low-tension network and the use of rotary converters needed further debate.

It appeared to him too late to discuss merely the technical merits of the rival systems. The matter was now a commercial one, as there was abundant business to be done in the world in polyphase apparatus, and up to the present this has been the only manufacturing country not competing for such business, whether due to a lack of the necessary commercial or technical experience, or of sufficient skilled workmen, or of the necessary manufacturing capital under our free trade conditions. The foreign firms, whose activity has led to this paper being read, supplied both types of motor, and whatever might be the correct answer to the questions raised by the author, it would not reduce their competition.

The stronghold of the direct-current motor appeared to be its efficiency; but this term is unfortunate in its abuse, there being many definitions, nearly all of which ignore light-load losses, and none are complete enough to indicate the nature of the compromises which have been made in the design of a motor. Prompt delivery, proper testing before delivery, real interchangeability of parts, and the durability of the motor-starting gear, in addition to the life and the efficiency of the motors themselves, interested purchasers, and it was not easy to get satisfaction on all these points. There appeared to be too many makers of direct-current motors in this country, *i.e.*, too many relatively small workshops manufacturing motors, judging by the success of the few—yet large—foreign firms.

Mr. Wyld.

Mr. W. WYLD, as one in charge of a three-phase plant, desired to say a few words. One speaker had told a terrible tale of how he saw the voltage vary on a polyphase plant on the Continent from 150 to 70 volts, but he had experienced nothing of that sort on his plant. He had some 500 H.P. of motors and about 400 incandescent lamps and 60 arc lamps, and by having this lighting pretty well balanced he did not experience any great variation in the voltage. His recording voltmeter sheets would, he thought, compare very favourably with those of any public supply central station. He ran his three-phase generators in parallel, and had not experienced the slightest trouble in this respect; they ran perfectly in parallel. It was comforting to hear Mr. Lindley speak of the polyphase motor as being mechanically ideal. One speaker had mentioned the small air space in the polyphase motor as liable to get filled with dust, etc. He had had no trouble from this, and there was not much chance of dust lodging in the space, as the draught caused by the rotor will not allow it to lodge there. With regard to the variation of speed, there were several cranes of from five to twenty tons worked by three-phase motors, and he had no trouble with the

speed regulation. This regulation was only used for short periods, so that the inefficiency of which so much has been said was not nearly so serious as was supposed. With regard to the paragraph in which Mr. Earle said that most of the Continental manufacturing firms are now engaged more on continuous than polyphase plant, he thought there was a general consensus of opinion among the members of the Institution who visited Switzerland last year that the Continental firms were more engaged upon polyphase plant, and in Mr. Fedden's Sheffield report, which had already been mentioned, it was stated that the German firms were more engaged on polyphase, particularly two-phase, than on continuous-current plant. In conclusion, he wished to express his certainty that had they adopted continuous instead of three-phase current the plant could not have given better results, even if it had given as good as had been obtained. Mr. Wyld.

Mr. H. EARLE, in reply, regretted that those interested in three-phase systems had not been more strongly represented in the discussion. He was much gratified that Mr. Miller, who, he knew, had carefully compared the two systems, agreed with him in the general conclusions he had drawn. Mr. Sayers' remarks as to the value of shunt regulation were very important, and he had himself adopted this economical method to increase the speed as much as 25 per cent. without unduly increasing the cost of the motor, and it admitted of very fine regulation without large resistance. Mr. Earle.

With regard to Mr. Wood's remarks respecting the small clearance in polyphase motors, this varied considerably, and it appeared to him that the difference allowed in the air-space by manufacturers was largely the cause of the varying power-factors met with.

He could not agreed with Mr. Lindley that continuous-current motors gave trouble, for if they were of good design and received proper attention they were to be entirely relied upon.

Mr. Whalley's contention that all unnecessary complication should be avoided was a right one; first costs had, however, to be considered, and where high-tension transmission and low-tension supply were adopted three-phase and direct current would have to be combined, till three-phase motors of a high power-factor were produced and they were so improved that they could compete on an equal footing with direct current.

Firms in this country had naturally turned their attention to that for which there was the best market, the necessary technical experience was available to take up any system which might prove to be the best, but up to the present time direct-current distribution had held its own against its rival.

He could not agree with Mr. Whalley respecting the unreliability of tests and figures of efficiency; these matters were most carefully attended to by all good firms, and it was only by attention to such matters that improvements in design could be effected, and makers were willing and able to supply motors to the strictest specifications.

Mr. Wyld's remarks were interesting, and he quite agreed that three-phase installations gave every success, though his examination of the subject had convinced him that when all points were considered direct-current offered many advantages.

ORIGINAL COMMUNICATION.

THE REGULATION OF THE POTENTIALS TO EARTH OF DIRECT-CURRENT MAINS.

By ALEXANDER RUSSELL, M.A., Member.

Introduction.—The regulation of the potentials to earth of the mains of a three-wire system of supply has become a subject of pressing importance, owing to the general adoption of higher pressures of supply. So long as the pressure between the outers of a three-wire system of supply was not greater than 250 volts, it was of no great importance what the pressure to earth of any of the mains was, as it was necessarily less than the Board of Trade limit of 250 volts. In this case it is inadvisable from the station engineer's point of view to alter the potentials of the mains to earth as, owing to electrical laws, they always assume the potentials that make the energy wasted in leakage currents a minimum. When, however, the difference of pressure between the outers is greater than 250, it is necessary to take reasonable precautions so that the potential from earth of any main may never rise for any lengthened period above 250 volts.

Mr. Wordingham has recently discussed the regulation of the potentials of the mains in his paper, "On the Maintenance of Certain Portions of Distributing Systems at Earth Potential," read at the Cardiff Convention of the Municipal Electrical Association, in the Summer of 1900. He there gives a clear description of certain causes which tend to lower the insulation resistance of the negative outer of a three-wire system.

For this reason the potential of the positive outer from earth is generally much higher than the difference of pressure between adjacent mains. In a large three-wire system, for example, the potentials of the mains are 190, 85, and —20 volts from earth respectively. If the pressure of supply were doubled, it is obvious that some method of lowering the potential of the positive outer would have to be adopted.

It will be instructive, therefore, to consider how these

potentials depend on the fault resistances of the mains, and what methods should be adopted for regulating them. It is a prevalent opinion that the measurement of the insulation resistance of a distributing network is a difficult process. It is in reality a very simple process, and many easy methods of doing it will be found described in Mr. Raphael's book on "The Localisation of Faults in Electric Light Mains." Another erroneous idea is that a knowledge of the insulation resistance of a network is of little importance. This is not the case, as it gives us definite information. It tells us, for example, that the power being wasted in leakage currents is less than a certain amount, and it also places a superior limit to the values of the leakage currents. As the Board of Trade rightly insists that the leakage current must not exceed a certain maximum value, any short way of finding a maximum possible value to the actual leakage currents is of importance, for if this maximum possible be less than the Board of Trade limit, the network obviously satisfies the regulations.

Fault Resistance.—By the fault resistance of a main we mean the resistance of all those stray paths from it to earth which do not pass through the other mains. Suppose the shunt coil of a badly insulated meter to be connected between the positive and the middle main, and suppose the potential of the latter to be positive, then the resistance of the leakage paths from this shunt coil to earth will all be credited to the fault resistance of the positive outer. If, however, it were connected between the negative outer and the middle, then some of the leakage paths of the shunt coil would be credited to one main, and the remainder to the other. We shall see later that an alteration in the fault resistance of the positive main will alter the potentials of them all, and theoretically will alter the fault resistances of the other two, owing to the point of zero potential on the wires connecting the middle and negative mains shifting. Again, theoretically speaking, every time a switch is turned on or off the fault resistances will be altered. When we say, then, that the fault resistances of the three mains are f_1, f_2, and f_3 respectively, it must be borne in mind that they may vary at different times of the day.

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Insulation Resistance.—If f_1, f_2, and f_3 be the fault resistances of the three mains, and F be the insulation

resistance of the network, then F is defined by the equation—

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3}.$$

We should expect F to remain approximately constant in practice, for when a switch is turned on between the positive and the middle, some of the leakage paths are taken from one main and given to the other. f_1 may be diminished and f_2 increased, but $\frac{1}{f_1} + \frac{1}{f_2}$ would remain approximately constant. Where, however,

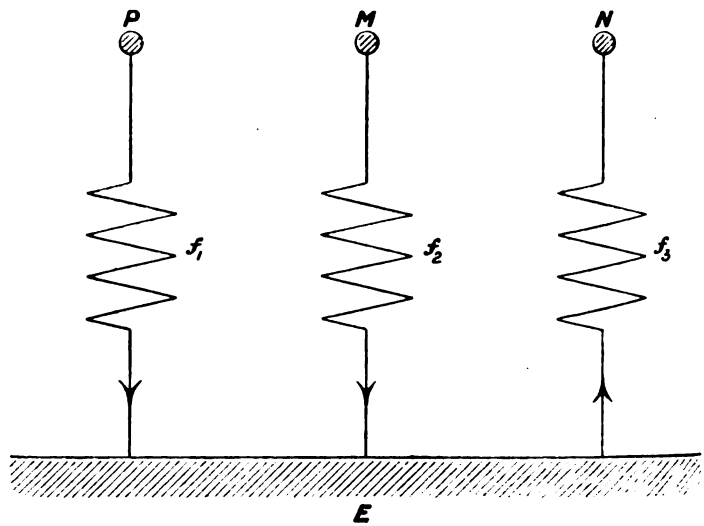

FIG. 1.

a double-pole switch is used for a leaky circuit, then, of course, F is diminished when the switch is turned on.

The Potentials of the Mains.—Let f_1, f_2, and f_3 be the fault resistances of the three mains P, M, and N (Fig. 1). Let also V_1, V_2, and V_3 be their potentials.

Then, by Kirchhoff's law—

$$\frac{V_1}{f_1} + \frac{V_2}{f_2} = \frac{V_3}{f_3} \quad . \; . \; . \; . \; . \; . \; . \quad (1)$$

If V be the P.D. between P and M and also between M

and N, then, since the dynamos maintain these P.D.'s constant—

$$\left.\begin{aligned} V_1 &= V_2 + V \\ V_3 &= V - V_2 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Substituting for V_1 and V_3 from (2) in (1), we easily find V_2 in terms of V, f_1, f_2, and f_3, and hence from (2) we also find V_1 and V_3.

Graphical Construction for the Potentials of the Mains.—Draw a line P N (Fig. 2) and make P M = M N = V.

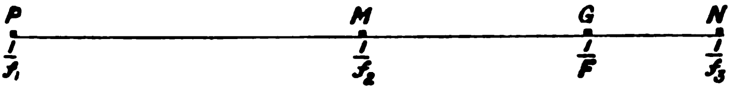

FIG. 2.

Place particles of mass $\frac{1}{f_1}$, $\frac{1}{f_2}$, and $\frac{1}{f_3}$ at P, M, and N respectively. Find their centre of gravity G. Taking moments about G, we see that—

$$\frac{PG}{f_1} + \frac{MG}{f_2} = \frac{NG}{f_3}.$$

$$\left.\begin{aligned} &\text{Also} \quad PG = MG + V \\ &\text{And} \quad NG = V - MG \end{aligned}\right\}$$

Comparing these equations with (1) and (2) above, we see that $PG = V_1$, $MG = V_2$, and $NG = V_3$.

In general, if we have n mains whose fault resistances are f_1, f_2, f_3, . . . and whose P.D.'s are maintained at V, V', V'', . . . respectively, then the potentials of the mains are given by the following construction. Draw a straight line and mark off along it points P_1, P_2, P_3, . . . whose distances apart are V, V', V'', . . . Place particles of mass $\frac{1}{f_1}$, $\frac{1}{f_2}$, $\frac{1}{f_3}$, . . . at P_1, P_2, P_3, . . . respectively, and let G be their centre of gravity, then—

$$V_1 = P_1G, \ V_2 = P_2G, \ . \ . \ .$$

Measurement of Insulation Resistance.—Read the voltage to earth of the middle main by means of an electrostatic voltmeter. Connect the middle main to earth by an

ammeter in series with a resistance. Let V_2 be the initial reading of the voltmeter and V'_2 the reading when the middle wire is earthed. Let also C be the reading on the ammeter, then—

$$F = \frac{V_2 - V'_2}{C}.$$

Example.—Initially V_2 was 112. When the middle was earthed, C was equal to 3·5 amperes and V'_2 was 8 volts, hence—

$$F = \frac{112 - 8}{3 \cdot 5},$$
$$= 29 \cdot 7 \text{ ohms.}$$

Proof of Formula.—Let PG, MG, and NG (Fig. 3) represent the initial potentials of the mains. We have

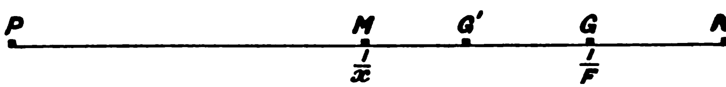

FIG. 3.

seen that G is the centre of gravity of masses $\frac{1}{f_1}$, $\frac{1}{f_2}$, and $\frac{1}{f_3}$ placed at P, M, and N respectively. We can replace these masses by a mass $\frac{1}{F}$ placed at G. Suppose now that a resistance x is connected between the middle and earth, then to find the new potentials we have to find the centre of gravity G′ of masses $\frac{1}{x}$ at M and $\frac{1}{F}$ at G.

Taking moments about G′—

$$\frac{MG'}{x} = \frac{GG'}{F};$$

$$\therefore \frac{V'_2}{x} = \frac{V_2 - V'_2}{F}.$$

But $\frac{V'_2}{x}$ is the current through the ammeter (C), hence—

$$F = \frac{V_2 - V'_2}{C}.$$

Another Method.—When V_2 is small, it is often more convenient to earth the positive outer through a resistance x. Let C be the current in this resistance, then we can prove in exactly the same way as we did the preceding formula that—

$$F = \frac{V_1 - V'_1}{C}.$$

Keeping Down the Potential of the Positive Outer by Earthing it or the Middle Main through a Resistance.—Suppose that we connect the positive outer to earth through a resistance x. To find the new potentials, we have to find the centre of gravity of masses $\frac{1}{x}$ and $\frac{1}{F}$ placed at P and G respectively (Fig. 4).

FIG. 4.

Taking moments about G′, we have—

$$\frac{V_2 - V'_2}{F} = \frac{V + V'_2}{x}.$$

But $\frac{V + V'_2}{x}$ is obviously the current through x, hence—

$$V_2 - V'_2 = F \,.\, C,$$

where C is the current in the artificial leak.

Again, to find the resistance x to be put in between the positive outer and earth in order to lower the potential of each main by v volts, we have—

$$C = \frac{v}{F} = \frac{V + V_2 - v}{x};$$

$$\therefore\ x = \frac{V + V_2 - v}{v} F.$$

If there was a dead earth on the negative outer, the maximum current through the resistance x would be $\frac{2V}{x}$.

Similarly we can show that if we earth the middle

wire through a resistance x, and if the current flowing through it be C, then—

$$C = \frac{V_2 - V'_2}{F}$$

$$= \frac{V'_2}{x}$$

$$= \frac{V_2}{F + x}.$$

Hence, as before—

$$V_2 - V'_2 = F \cdot C.$$

To lower the pressure, therefore, by v volts, the resistance of the earth connection of the middle wire must be $\frac{V_2 - v}{v} F$ ohms. The current that will flow in it will be $\frac{v}{F}$ amperes. If there is a dead short on either of the outers, the greatest current through the earth connection will be $\frac{V}{x}$ amperes.

Example.—Suppose that initially $V_1 = 300$, $V_2 = 100$, and $V_3 = -100$ volts, and suppose also that $F = 10$ ohms. It is required to calculate the resistance x of the earth connection to be put (1) between the positive outer and earth, and (2) between the middle main and earth, in order to reduce the pressure of the positive outer to 250 volts.

(1) By the above formulæ—

$$x = \frac{100 + 200 - 50}{50} \cdot 10$$

$$= 50 \text{ ohms.}$$

In this case, if the negative outer were dead-earthed, the greatest current through x would be 8 amperes.

(2) When x is put between the middle and earth, then to lower the potential 50 volts we must have—

$$x = \frac{100 - 50}{50} \cdot 10$$

$$= 10 \text{ ohms.}$$

If either of the outers be short-circuited, the maximum possible current through x is 20 amperes.

The expenditure of power in the first case would be greater than in the second by V C watts, *i.e.*, by a kilowatt. This, however, might be utilised at the station.

The Energy Expended in Earth Currents in the Mains of Distributing Systems.—The algebraical expression for this energy is—

$$\frac{V_1^2}{f_1} + \frac{V_2^2}{f_2} + \frac{V_3^2}{f_3}.$$

If we use the graphical construction shown in Fig. 2, it is—

$$\frac{PG^2}{f_1} + \frac{MG^2}{f_2} + \frac{NG^2}{f_3}.$$

Now if we regard the position of G as variable, then by a well-known statical theorem this expression is a minimum when G is the centre of gravity of masses $\frac{1}{f_1}$, $\frac{1}{f_2}$, and $\frac{1}{f_3}$ placed at P, M, and N respectively. But we know that this is how the potentials adjust themselves in practice, and hence they adjust themselves so that the energy expended is a minimum. This theorem is true for n-wire systems. Let x be the potential of the positive outer, then the energy expended in leakage currents is—

$$\frac{x^2}{f_1} + \frac{(x - V)^2}{f_2} + \frac{(x - V - V')^2}{f_3} + \dots .$$

Now by Kirchhoff's law—

$$\frac{x}{f_1} + \frac{x - V}{f_2} + \frac{x - V - V'}{f_3} + \dots = 0.$$

But by the Differential Calculus, this is the condition that—

$$\frac{x^2}{f_1} + \frac{(x - V)^2}{f_2} + \frac{(x - V - V')^2}{f_3} + \dots .$$

should be a minimum, hence the theorem follows.

Again—

$$\frac{V_1^2}{f_1} + \frac{V_2^2}{f_2} + \frac{V_3^2}{f_3} = \frac{(V + V_2)^2}{f_1} + \frac{V_2^2}{f_2} + \frac{(V_2 - V)^2}{f_3}$$

$$= \frac{V^2}{f_1} + \frac{V^2}{f_3} - \frac{V_2^2}{F}.$$

Now if we connect the middle wire directly to earth, the power expended in earth-leakage currents is $\frac{V^2}{f_1} + \frac{V^2}{f_3}$. The loss of power in earth currents has therefore been increased by $\frac{V_2^2}{F}$. In the example given above, V_2 is 100 and F is 10, hence the extra power lost by earthing the middle wire is a kilowatt. In some of the older 100-volt three-wire systems, F is only two or three ohms, and there have been cases where it has even been less. In these cases the loss of power entailed by earthing the middle wire would be appreciable.

If we earth the middle wire through a resistance x, then the new values of V_2 and F are given by the equations—

$$V'_2 = V_2 \frac{x}{F + x}$$

and—

$$\frac{1}{F'} = \frac{1}{F} + \frac{1}{x}.$$

Therefore the increased loss of energy in this case is—

$$\frac{V_2^2}{F} - V_2^2 \frac{x^2}{(F + x)^2}\left(\frac{1}{F} + \frac{1}{x}\right) = \frac{V_2^2}{F + x}.$$

Effect of Earthing the Middle Main through a Battery.—Suppose that the middle main is at positive potential. Connect the negative pole of a battery to it (Fig. 5) and the positive pole through a resistance to earth. Let E be the E.M.F of the battery, and let x be the resistance from the middle main to earth through the battery. Then by Kirchhoff—

$$\frac{V'_1}{f_1} + \frac{V'_2}{f_2} + \frac{V'_2 + E}{x} = \frac{V'_3}{f_3}.$$

Exactly as before we can show that if we draw a line P M N and make $PM = MN = V$ (Fig. 6), and also $MX = E$, then, if we place masses $\frac{1}{f_1}$, $\frac{1}{x}$, $\frac{1}{f_2}$, and $\frac{1}{f_3}$ at

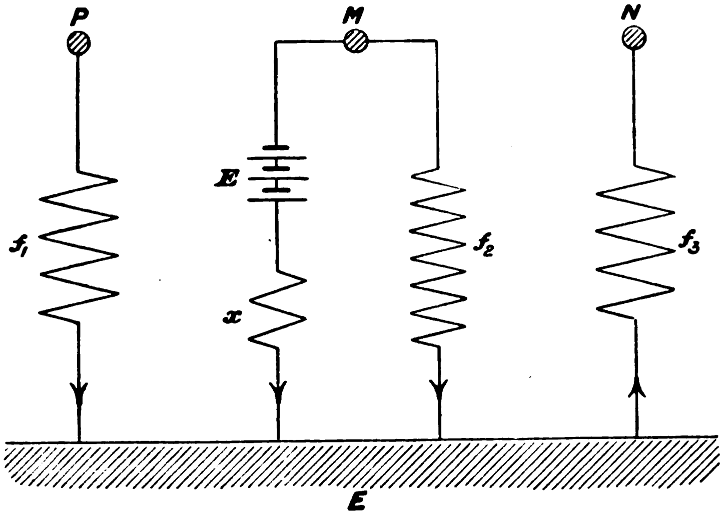

FIG. 5.

P, X, M, and N respectively, and if we find G′ the centre of gravity of these masses, then—

$$V_1 = PG'; \quad V_2 = MG'; \quad \text{and } V_3 = NG'.$$

Let G be the centre of gravity of $\frac{1}{f_1}$, $\frac{1}{f_2}$, and $\frac{1}{f_3}$, so that

FIG. 6.

we may suppose $\frac{1}{F}$ placed at G, then—

$$PG = V_1; \quad MG = V_2; \quad \text{and } NG = V_3.$$

Taking moments about G′—

$$\frac{V_2 - V'_2}{F} = \frac{V'_2 + E}{x}.$$

Hence—

$$V'_2 = \frac{\frac{V_2}{F} - \frac{E}{x}}{\frac{1}{F} + \frac{1}{x}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

Also the current C through the battery is given by—

$$C = \frac{V'_2 + E}{x} = \frac{V_2 - V'_2}{F} = \frac{V_2 + E}{F + x} \quad . \quad . \quad (b)$$

We have supposed that E is acting in the same direction as V_2. If we connect the battery so that E opposes V_2, then we shall have to alter the sign of E in formulæ (*a*) and (*b*).

Formula (*a*) shows us that by means of a battery we can lower the potential of the mains more rapidly than we could by means of the resistance x alone. If we choose E so that it is equal to kV_2, and x so that it equals kF, where k is any number, then V'_2 will be zero. For example, if V_2 equals 50 and F equals 100, then making E equal to 25 and x equal to 50, we could reduce the middle wire to zero potential. In this case the current through the battery would be half an ampere, and the power it would be giving out would be 12·5 watts. In general, when the middle wire is at zero potential, the current through the earth connection will be $\frac{V_2}{F}$ amperes, and if there is a battery in this circuit, the power it will be expending will equal $E\frac{V_2}{F}$.

In several cases in practice it appears to be desirable to keep the middle main negative to earth. This can be done by a battery as above, or by connecting the positive outer to earth through a resistance. The expenditure of power in the earth connection in the latter case is to its expenditure in the former case as $V - e$ is to $E - e$, where $-e$ is the potential of the middle main. Another way of keeping the potential of the middle wire negative would be to use a motor-dynamo, the motor terminals being connected across the two outers and the dynamo terminals being in series with the earth connection of the middle wire.

Partial Earthing of the Outers.—One of the most effectual methods of regulating the potentials of the mains would be to connect the middle to earth through a very small resistance, and to have two variable resistances connected between the outers and earth. In the event of an earth occurring in either outer, then by cutting down the resistance between the other outer and earth we could regulate the potentials. In the case of a bad earth, considerable power would have to be expended in earth currents, and as these currents might cause serious damage, either by starting a fire or electrolytically, we shall consider the values of the leakage currents that are at present considered allowable.

Leakage Currents.—It is important to notice that all the methods described of preventing the potentials of the mains from rising above 250 volts increase the leakage currents to earth. As these currents are always flowing, it is desirable to keep them as small as possible owing to the electrolytic damage they may do. In the Board of Trade conditions for the approval of earthing it is provided that a record of the current to earth through the earth connection shall be kept, and that if at any time it exceeds the one-thousandth part of the maximum current of supply, immediate steps shall be taken to improve the insulation of the system. Now the current that is measured in this case is the difference between the leakage currents from the positive and negative mains. If the fault resistances of the whole three mains be very bad, as has sometimes happened owing to the insulating rubber having become rotten, yet if the fault resistances of the two outers be nearly equal, then the current in the earth connection may be very small, or it may even be zero. A better rule would be to insist that the insulation resistance "F" of the network, when the earth connection is removed, must always be above a certain amount. In order to get an idea of what this value of "F" should be, we will discuss the eighth of the Board of Trade Regulations (A). This regulation is as follows :—

> "8. *Maintenance of Insulation.*—The insulation of every complete circuit used for the supply of energy, including all machinery, apparatus and devices forming part of, or in connection with, such circuit, shall be so maintained that the leakage current shall not under any

conditions exceed one-thousandth part of the maximum supply current; and suitable means shall be provided for the immediate indication and localisation of leakage. Every leakage shall be remedied without delay.

"Every such circuit shall be tested for insulation at least once in every week, and the undertakers shall duly record the results of the testings.

"Provided that where the Board of Trade have approved of any part of any electric circuit being connected with earth, the provisions of this regulation shall not apply to that circuit so long as the connection with earth exists."

Now for a two-wire system this rule is clear. It proceeds on the assumption that the permissible leakage power must always be the same fraction of the total output. In other words, if we double the pressure of supply (the output remaining the same) the lowest permissible value of the insulation resistance is increased four times. Hence systems of supply are treated equitably from the fire-risk point of view. The systems, however, that use lower pressures are allowed to have larger leakage currents, and in the course of time the electrolytic damage done by them may be appreciable. It is desirable also that even when systems are dead-earthed through a connection, that this connection should be removable, so that the insulation could be tested once a week.

When we come to apply the above rule to three-wire networks we are met with the difficulty that the determination of f_1, f_2 and f_3 is not easy, and hence there is no simple rule to give us the earth-leakage currents from the three mains. There is also no practical method of determining the leakage currents that do not pass through earth. What we can determine easily is F the insulation resistance to earth of the network, and the potentials V_1, V_2 and V_3 of the three mains. The question then arises, having given the potentials of the mains and the insulation resistance of the network, can we determine the maximum possible value of any one of the earth-leakage currents, and the maximum possible value of the leakage watts expended in producing them? If we know these maximum values, then we can fix on a minimum permissible value to "F" in any given case. Of course it would be more satisfactory actually to deter-

mine the values of f_1, f_2 and f_3, but the ordinary methods are tedious and not very accurate in practice.

Let V be the P.D. between adjacent mains, V_2 the potential of the middle main, and "F" the insulation resistance of the network. We have to find out what the maximum possible earth current is in this case. It is easiest to do this graphically. Looking at Fig. 2 we see that G is fixed, and so also is the sum $\left(\frac{1}{F}\right)$ of the three masses. We want to find when $\frac{V_3}{f_3}$ is a maximum. Now this is the moment about G of the mass at N, and we have therefore to find the maximum value of this moment. It obviously has its maximum value when the mass at M is zero. In this case—

$$\frac{1}{f_1} + \frac{1}{f_3} = \frac{1}{F}\ ; \text{ C max.} = \frac{V_1}{f_1} = \frac{V_3}{f_3}$$

And therefore—

$$\text{C max.} = \frac{V - V_2}{F} \cdot \frac{V + V_2}{2V} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Similarly, if C min. be the smallest value that the greatest of the earth currents can have in any given case, then—

$$\text{C min.} = \frac{V - V_2}{F} \cdot \frac{V_2}{V} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Again, since P the leakage watts expended in earth currents is given by the equation—

$$P = \frac{V^2 - V_2^2}{F} - \frac{V^2}{f_2}$$

$$\text{P max.} = \frac{V^2 - V_2^2}{F} = 2\,\text{V C max.} \quad . \quad . \quad . \quad . \quad (3)$$

And—

$$\text{P min.} = \frac{V_2(V - V_2)}{F} = \text{V C min.} \quad . \quad . \quad . \quad (4)$$

Suppose now that we earth the middle wire of this system through a resistance of x ohms. The new potential V'_2 of the middle wire will be given by—

$$V'_2 = V_2 \frac{x}{F + x} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

And it is easy to show that,

$$C \text{ max.} = \left(V - V'_2\right) \frac{V + V_2}{2 V F}$$

$$= \left(V - \frac{x}{F + x} V_2\right) \frac{V + V_2}{2 V F} \quad . \quad . \quad . \quad . \quad (6)$$

$$C \text{ min.} = \left(V - \frac{x}{F + x} V_2\right) \frac{V_2}{V F} \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

$$P \text{ max.} = \frac{V^2}{F} - \frac{x}{F + x} \frac{V_2^2}{F} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$P \text{ min.} = \frac{V V_2}{F} - \frac{x}{F + x} \frac{V_2^2}{F} \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

In the particular case when the middle wire is dead-earthed, then—

$$C \text{ max.} = \frac{V + V_2}{2 F} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

$$C \text{ min.} = \frac{V_2}{F} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

$$P \text{ max.} = \frac{V^2}{F} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

$$P \text{ min.} = \frac{V V_2}{F} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

The above formulæ show that whether we earth the middle wire or not, $\frac{V + V_2}{2 F}$ and *a fortiori* $\frac{V}{F}$ is a superior limit to an earth current, and that $\frac{V^2}{F}$ is a superior limit to the power expended in earth-leakage currents. This latter result is known and is proved in another manner in a paper by the author on "Insulation Resistance and Leakage Currents," which appeared in the *Electrician*, vol. 41, p. 206.

The following numerical examples show how these results can be applied in practice :—

(1) The maximum output of a three-wire direct-current station with 200 volts between the outers is 3,000 kws. What is the lowest insulation resistance which would ensure that no earth-leakage current is greater than the thousandth

part of the maximum supply current, the potential of the middle main being 20 volts?

In this case $V = 100$, $V_2 = 20$, the maximum current of supply is 15,000 amperes, and therefore—

$$C \text{ max.} = 15.$$

Substituting these values in formula (1)—

$$15 = \frac{80}{F} \cdot \frac{120}{200};$$
$$\therefore F = 3{\cdot}2 \text{ ohms.}$$

And from (3)—

$$P \text{ max.} = 3 \text{ kws.}$$

Suppose now that the middle wire was dead-earthed, then from (10)—

$$15 = \frac{100 + 20}{2F};$$
$$\therefore F = 4 \text{ ohms.}$$

And from (12)—

$$P \text{ max.} = 2{\cdot}5 \text{ kws.}$$

(2) Suppose now that the pressure was increased so that the P.D. between the outers was 500 volts, what must the insulation resistance be in this case?

Supposing that the output is the same as in the last case, then since the voltage has been increased $2\frac{1}{2}$ times the maximum earth current must not be greater than 6 amperes, and F must be $(2{\cdot}5)^2$ times as great as in the last example, *i.e.*, 20 ohms. When the middle wire is dead-earthed, then F must be greater than 25 ohms.

In practice, however, the maximum output would be increased 6·25 times, and the maximum permissible earth current would therefore be 37·5 amperes. Hence the insulation resistance of the network need only be the same as when there was 200 volts between the outers. The lowest permissible value of "F" would therefore be 3·2 ohms, and when the middle was earthed 4 ohms. Most electricians would regard these values as too low.

(3) The potentials of the mains of a three-wire direct-current system are 300, 100, and -100 volts respectively,

and its insulation resistance is 10 ohms, between what limits must (*a*) the greatest of the earth currents and (*b*) the power expended in earth currents lie? If the middle wire be earthed through a two-ohm resistance, what are now these limits, and what are the new potentials of the mains?

By formulæ (1), (2), (3), and (4) we at once prove that—

C max. = 7·5 amperes. P max. = 3 kws.
C min. = 5 amperes. P min. = 1 kw.

Again from (5)—

$$V'_2 = \frac{x}{F + x} V_2$$
$$= 16\cdot7 \text{ volts.}$$
$$\therefore V'_1 = 216\cdot7,\ V'_2 = 16\cdot7, \text{ and } V'_3 = -183\cdot3.$$

By formulæ (6), (7), (8), and (9)—

C max. = 13·75. P max. = 3·83 kws.
C min. = 9·17. P min. = 1·83 kws.

$$\text{The current in the earth connection} = \frac{V'_2}{x}$$
$$= \frac{V_2}{F + x}$$
$$= 8\cdot33 \text{ amperes.}$$

(4) The potentials of the mains of a three-wire direct-current distributing system are 190, 85, and −20 volts respectively, and its insulation resistance is 2·5 ohms. Find the limits between which the earth currents to the negative main must lie, and also the limits for the leakage power.

By the formulæ—

$$\text{C max.} = \frac{105^2 - 85^2}{210 \times 2\cdot5} = 7\cdot24 \text{ amperes.}$$

$$\text{C min.} = \frac{85 \times 20}{105 \times 2\cdot5} = 6\cdot48 \quad \text{,,}$$

Whatever the values of the fault resistances may be, the leakage current to the negative main lies in value between 6·48 and 7·24 amperes.

Also, P max. = 1·52 kws. and P min. = 0·68 kws.

If we were to earth the middle main, then the current to the negative main would lie between 38 and 34 amperes, and the power expended in leakage earth currents would lie between 4·41 and 3·57 kws. The current in the earth connection also would be 34 amperes. In this case there would be obviously nothing to gain by earthing the middle wire. On the contrary, the current to the negative would now be doing five times the amount of electrolytic damage, and we should be wasting about three kilowatts all the year round.

The Board of Trade Regulation (A. 8) was framed to meet the danger of fire-risk, and is a scientific rule founded on certain assumptions as to the laws that govern the progress of electric lighting. When we are considering three-wire or five-wire systems, however, it is difficult to apply it, and the raising of the pressure of the supply and the enormous growth of supply net-works have brought other considerations to the front. The danger to the public now lies rather from possible shocks or from the corrosion of pipes by leakage currents. The rule for the insulation resistance of the various private installations looks after the fire-risk.

It might be advisable in the best interests of the electric lighting industry to have a return taken of the insulation resistance of all the three-wire networks in this country. By what has been shown above, the mere measurement of V_2 and F need only take a few minutes, and can be done from any point on the network when the earth connection from the middle main is removed. With the help of the formulæ given above, a simple rule might then be devised which would safeguard the interests of the public and be acceptable to station engineers.

Summary.—The following are the most important points in this paper :—

(1) A graphical method of finding the potentials of the mains from their fault resistances. This construction simplifies the proof of many important theorems.

(2) A simple method of measuring insulation resistance.

(3) A discussion of various ways of keeping down the potential of the positive outer. All of these methods, however, effect this by increasing the leakage currents.

and its insulation resistance is 10 ohms, between what limits must (*a*) the greatest of the earth currents and (*b*) the power expended in earth currents lie? If the middle wire be earthed through a two-ohm resistance, what are now these limits, and what are the new potentials of the mains?

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(3) A discussion of various ways of keeping down the potential of the positive outer. All of these methods, however, effect this by increasing the leakage currents.

(4) When the middle main is earthed through a connection, it ought always to be removable, so that the insulation resistance could be accurately found.

(5) A discussion of the allowable leakage currents. Knowing V, V_2, and F, it is shown that the maximum earth current must lie between certain limits. These limits and the limits for the leakage watts expended in earth currents are given when the middle wire is earthed through a resistance of x ohms.

(6) When the potential of the positive outer is above 250 volts, then the higher the insulation resistance of the system the easier it is to keep it down to 250 volts. If it be required to reduce the potential of the outer by v volts, then if we connect the middle to earth through a resistance of $\frac{V_2 - v}{v} F$ ohms, this will be done, and the current in this earth connection will be $\frac{v}{F}$ amperes.

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VOL. XXX. 1901. No. 149.

The Three Hundred and Fifty-sixth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, January 10th, 1901—Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on December 20th, 1900, were read and confirmed.

The Secretary read the following letter from Colonel Crompton :—

"THRIPLANDS,
"KENSINGTON COURT,
"W.
"*December 28th*, 1900.

"The Secretary,
"Institution of Electrical Engineers,
"28, Victoria Street,
"Westminster.

"SIR,

"I have the honour to acknowledge the receipt of your letter of December 20th, in which you inform me of the Resolution proposed by Mr. Alex. Siemens, and carried by the Institution, congratulating the Corps of Electrical Engineers on their South African services. I will take steps to ensure that every member of the corps is acquainted with the kind action of the Institution in this matter.

"In return, on behalf of the Officers, Non-Commissioned Officers, and Sappers of the corps, I beg to thank the Institution, not only for their kind expressions of sympathy with us, but also for all they have done for us in the past, which has been of most material assistance to us in rendering our services of use to the country.

"Very faithfully yours,
"R. E. CROMPTON,
"Lt.-Col., E.E."

The names of new candidates for election into the Insti-

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"Very faithfully yours,
"R. E. CROMPTON,
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The names of new candidates for election into the Insti-

tution were announced, and it was ordered that the list should be suspended in the Library.

The following transfers were announced as having been approved by the Council:—

From the class of Associate Members to that of Members—

Frederick William Anthony Knight.	William Stevenson.
	Stephen John Watson.

From the class of Associates to that of Members—

Henry Walter Jenvey.

From the class of Associates to that of Associate Members—

Gerald Ricketts Blackburn.	Cyril Napier Probyn Raikes.
William Brew.	Noel Burn Rosher.
Arthur Blackburn Child.	R. J. Jocelyn Swan.
Julian A. Halford.	Robert Naudin Tweedy.
Gilbert J. Lloyd.	John Walton.

Richard Wightman.

From the class of Students to that of Associates—

John Tiernay Callaghan.	Francis Samuel Miller.
Fred Leslie Cruikshanks.	John Leslie Morris.
Mostyn R. Gardner.	Frederick Walter Purse.
Benjamin Handley.	W. A. Quennell.
Frank John Hawkins.	C. T. Stephenson.
Bernard Hopps.	Clement Erskine Vines.
Elias Marcuson.	Andrew Cyril Weber.

Donations to the Library, Building Fund, and Benevolent Fund were announced as having been received since the last meeting:—To the *Library* from Mr. H. W. Lindley, Mr. E. G. Mawbey, and Mr. H. W. Jenvey, Associate. To the *Building Fund* from Messrs. W. Duddell, John Rann, Capt. Jackson, J. E. Stewart, J. F. C. Snell, C. Bauer, A. E. Levin, Alfred Hay, Thomas Mills, Dr. du Riche Preller, R. A. Dawbarn, A. Rutherford, K. W. Fiddian, S. Roget, W. H. Shephard, A. Stroh, A. A. C. Swinton, H. W. Young, F. A. Glover, Joshua Shaw, E. Percy Harvey, Francis Milton, F. W. Topping, F. H. Nicholson, J. M. Donaldson,

Algernon Burton, W. M. Rolph, W. Sankey, W. Golledge, L. R. Morshead, John T. Haynes, H. J. Humphreys, Frank S. Miller, A. G. Jeffreys, W. J. Cooper, A. B. Crinks, J. M. Smyth, A. C. Makovski, L. Redmayne, E. D. Morgan. To the *Benevolent Fund* from Sir David Salomons, and Messrs. A. E. Levin, O. M. Andrews, S. Roget, A. Stroh, E. Percy Harvey, W. G. Shee, Killingworth Hedges; to whom the thanks of the meeting were duly accorded.

Messrs. F. H. Varley and G. C. Allingham were appointed scrutineers of the ballot for the election of new members.

The President announced that the following had been appointed the Committee of the Birmingham Local Section for the ensuing year:

OFFICERS AND COMMITTEE OF THE BIRMINGHAM LOCAL SECTION.

Chairman: Professor Oliver Lodge, D.Sc., F.R.S.
Vice-Chairman: Henry Lea.

Committee:

F. Brown.	Capt. H. R. Sankey.
A. Coleman.	W. E. Sumpner, D.Sc.
A. Dickinson.	R. Threlfall, F.R.S.
G. S. Ram.	J. C. Vaudrey.

W. Wyld.

Hon. Secretary: D. K. Morris, Ph.D.

The PRESIDENT: I have to announce that the Inaugural Meeting of the Birmingham Section will take place on Wednesday, January 23rd. Your President and the Secretary will, of course, attend that meeting. I also announce to you the formation of our first Local Section in India, the Calcutta Local Section of the Institution of Electrical Engineers.

It was, further, announced that the Council had agreed that, for the present, the areas of three local sections should be as follows:—

Birmingham: The counties of Staffordshire, Warwickshire, and Worcestershire.

Dublin: An area defined by a circle with a radius of twenty-five miles from Dublin (with the understanding that in special cases where a more distant

member proposes to attend the meetings of the Section, such cases should be specially considered by the Committee of the Section, and the member claimed if it is thought right).

Newcastle-on-Tyne: The counties of Northumberland, Durham, and Cumberland, with the town of Middlesbrough and Cleveland District.

The following paper was then read :—

THE USE OF ALUMINIUM AS AN ELECTRICAL CONDUCTOR, WITH NEW OBSERVATIONS UPON THE DURABILITY OF ALUMINIUM AND OTHER METALS UNDER ATMOSPHERIC EXPOSURE.

By JOHN B. C. KERSHAW, F.I.C.

I. INTRODUCTION.

The high price to which copper has been forced in recent years by a combination of natural and artificial causes—a combination which it is unnecessary to discuss in this paper—has led to a renewed interest in aluminium as a substitute for copper in electrical power transmission schemes.

Ten years ago the price of aluminium was 8s. 4d. per lb., and its use as a substitute for copper for electrical purposes even with the latter metal at £80 per ton, was therefore economically impossible. The purity of the metal manufactured in the early days of the electro-metallurgical process, by which the whole of the supply of the metal is now produced, was also variable; and it is only within the last few years that the improvements in the process of manufacture, in their relation to the quality and price of the metal produced, have brought aluminium within the practical range of the electrical engineer as a substitute for copper.

The following table shows that the price of aluminium has fallen and the quality has improved with increasing output, each year since 1890, when the present electro-

metallurgical process of manufacture was first adopted in this country.

TABLE I.

World Production and Average Price of Aluminium, each Year for the Period 1890–1900.

Year.	Production in Metric Tons of 2,204 lbs.[1]	Price in Pence per lb. in U.S.A.	Quality.[2]
1890	165	...	
1891	233	75	
1892	487	49	
1893	715	37	·93 to 1·64 % Silicon, ·32 to 1·66 % Iron
1894	1,240	30	
1895	1,418	27½	
1896	1,789	20	
1897	3,394	17½	
1898	4,033	16⅕	·02 to 13 % Silicon, ·12 to ·32 % Iron
1899	5,000 (Estimated)	16⅕	

II. Relative Costs of Copper and Aluminium.

In order to compare the price of aluminium with that of copper when used for conducting purposes, it is necessary to make allowance for the fact that the Specific Gravity of aluminium is rather less than one-third that of copper, and that its conductivity for wires of equal sectional area is only from 50–63 per cent. that of the more common metal. The following formula is useful for calculating the relative prices of equal lengths of bare conductors of the two metals, of equal electrical capacity :—

$$\frac{S \times P \times c}{s \times p \times C}$$

[1] From *The Mineral Industry*, vol. viii., 1900.
[2] Moissan's tests, *Comptes Rendus*, 1898.

In this S, P, and C represent the Specific Gravity, Price, and Conductivity of Copper, while s, p, and c represent the corresponding values for aluminium.

Taking the most reliable values for the physical constants of the two metals, and the most recent market prices, namely—

S	8·93	s	2·68
C	100	c	59
P	£91 per ton	p	£224 per ton

and inserting these in the formula given above, we obtain the following price ratio :—

$$\frac{8{\cdot}93 \times 91 \times 59}{2{\cdot}68 \times 224 \times 100} = \frac{798}{1000} = \frac{\text{Cu.}}{\text{Al.}}$$

Expressing this ratio in another manner, £798 expended upon copper will equal £1,000 expended upon aluminium for the same length of wire of equal carrying capacity; and aluminium is, therefore, much the dearer metal of the two.

Special rates are, however, offered where large quantities of aluminium are taken in rod or wire form for electrical purposes, and in the United States large quantities of the new metal have been sold at 29 cents per lb. = £135 per ton.[1]

Using this figure in the formula given above, the cost ratio for conductors of equal length and equal carrying capacity becomes—

$$\frac{8{\cdot}93 \times 91 \times 59}{2{\cdot}68 \times 135 \times 100} = \frac{1325}{1000} = \frac{\text{Cu.}}{\text{Al.}}$$

and copper is seen to be the more costly material.

III. Installations of Aluminium in the United States and in the United Kingdom.

The low price at which aluminium is being sold for conducting purposes in America therefore explains the

[1] Messrs. T. Bolton & Sons inform the writer that in this country £170 per ton is quoted for large orders of the wire.

readiness of electrical engineers in that country to adopt the new metal. It may be explained here that at present there is no talk of using aluminium for insulated conductors; the greater sectional area of the metal for equal carrying capacity (1·68 : 1·00) rendering it impossible to use it for such covered conductors, until it has fallen to a much lower price relative to copper.

The following are the particulars of some of the bare aluminium transmission lines already completed across the Atlantic.

At Niagara Falls there are two aluminium transmission lines; the one conveying current from the generating station to No. 2 Works of the Pittsburg Reduction Company, and the other conveying current to the Chlorate Works of the National Electrolytic Company. Both these lines are short, and are stated to be working satisfactorily. Together they transmit 4,000 H.P.

The Hartford Electric Light and Power Company have an aluminium line between their generating station at Tariffville, and Hartford—a distance of 11 miles. About 2,000 H.P. is transmitted at 10,000 volts pressure by the three-phase system, over this line. The diameter of the stranded cable used is ¾ inch, and it weighs about 1,500 lbs. per mile.

The aluminium transmission line of the Snoqualmie Falls Power Company has been frequently described in the technical press. It runs between the Falls and the two towns of Tacoma and Seattle. Its total length is 34 miles. When the scheme is completed, 10,000 to 12,000 H.P. will be transmitted by this line at a pressure of 29,000 volts. The aluminium used has been alloyed with 1½ per cent. of copper, and the increased tensile strength of this alloy has enabled spans of 120–150 feet to be safely used.

The Blue Lakes Power Company have an aluminium line in use between their power-house at Blue Lakes, and Stockton—a distance of 36 miles; 1,000 H.P. being transmitted by the three-phase system at a pressure of 25,000 volts. The line originally erected has been replaced by one of greater carrying capacity, and 1,000,000 lbs. (446 tons) of the metal have been used for the new line. At 29 cents per lb. this represents an outlay of £60,400 (or £1,677 per mile) for the metal alone.

One of the most interesting of the power transmission schemes in U.S.A. for which aluminium is used, is that of the Telluride Power Company. This Company generates current at Provo, in Utah, and distributes it over an 80-mile circuit to the mines at Mercur and at Tintic. 2,000 H.P. was originally transmitted at 40,000 volts, but plans for increasing this amount of power are being proceeded with, and it is intended later to use a pressure of 60,000 volts.

Other Power Companies in America, in connection with which aluminium is used, or is about to be used, in place of copper, are the following:—

1. North Yuba Power Company, supplying 1,000 H.P. to Sacramento from a generating station 63 miles distant.
2. The Municipal Supply Company, supplying 2,000 H.P. to Orillia, Ontario, from a generating station at Ragged Rapids, 18 miles distant.
3. The Big Cotton-Wood Power Company, supplying Utah with 500 H.P.
4. The Standard Electric Company. The Company has been floated to develop a scheme for supplying San Francisco from a generating station in the Sierra Nevada Mountains, 150 miles distant. The success of this project depends upon the possibility of using and maintaining the proposed pressure of 60,000 volts. It has been decided to use aluminium cables for the scheme; and estimates have been prepared.

In addition to the power-transmission lines named above, aluminium is being used in place of copper for conducting purposes by the Waxahachie Electric Light Company, of Texas; by the North-Western Elevated Railroad Company, of Chicago; by the Kansas City and Leavenworth Electric Railroad Company; and by the Manhattan Elevated Railroad Company, of New York. For telephonic and similar purposes it is in use by the Pennsylvania Railroad Company, by the Pacific States Telegraph and Telephone Company, and by the New York Telephone Exchange. In this country the Northallerton

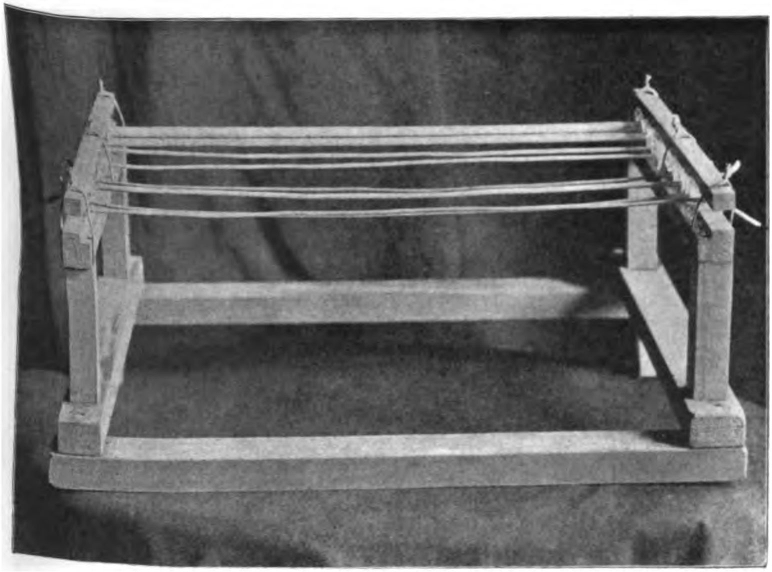
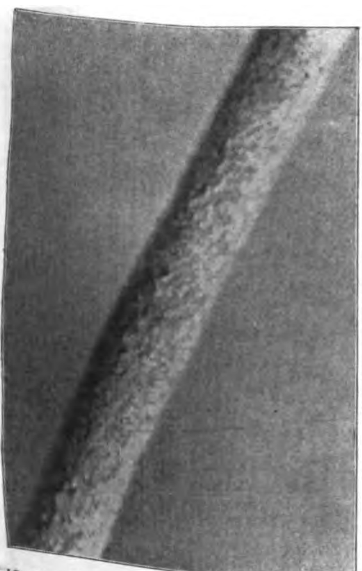


FIG. 1.—Frame used for Wire Exposure Tests.



IG. 2.—Corrosions on Surface of Aluminium Wire. Magnified 4 times.

FIG. 3.—Corrosions on Surface of Aluminium Wire. Magnified 20 times.

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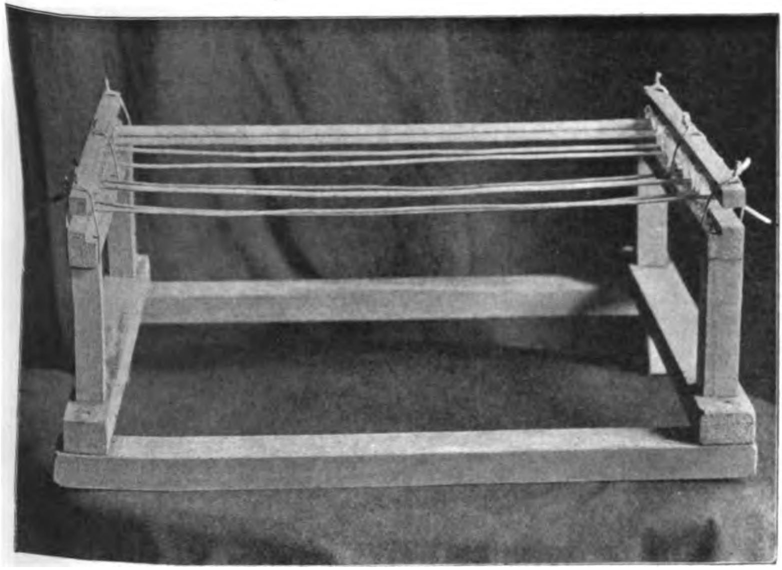

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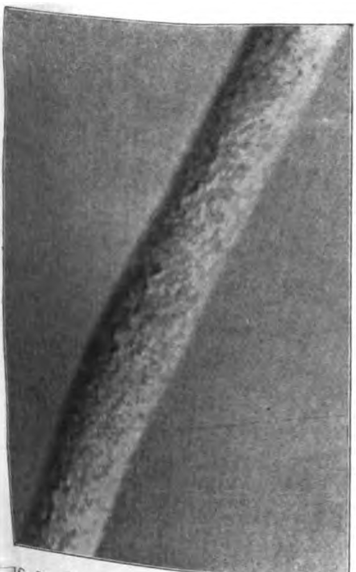


IG. 2.—Corrosions on Surface of Aluminium Wire. Magnified 4 times.

FIG. 3.—Corrosions on Surface of Aluminium Wire. Magnified 20 times.

Electric Lighting Company have four miles, and the British Aluminium Company, at their Foyers Works, have several miles of aluminium in use for various purposes; and the Post Office authorities are making experimental trials of the metal for long-distance telephonic communication.

The difficulty of soldering aluminium has been surmounted in most of these schemes by using mechanical joints, the MacIntyre sleeve-joint being that usually adopted. In one or two cases, as at Niagara and at Northallerton, soldered-joints have been made, but the writer doubts whether these will prove as satisfactory.

This summary of the chief installations of aluminium as an electrical conductor in the United States and in this country, shows that considerable progress has been made. In time the metal, *if it be found to possess the requisite durability*, may become an important rival of copper in this new field of usefulness.

IV. Durability of Aluminium and other Metals under Atmospheric Exposure.

The old idea that aluminium was absolutely proof against attack by all agents excepting alkalies and hydrochloric acid is now known to be incorrect; and Ditte in communications made to the Academie des Sciences[1] has shown that aluminium is easily attacked and corroded by air and water under certain conditions. It is therefore of considerable importance to inquire whether these conditions are present when aluminium is used as a bare conductor for overhead lines, and is exposed to all the varieties of weather that we experience in the course of the four seasons of the year. In America electrical engineers are conducting this inquiry in the usual American fashion; and their installations of aluminium for transmission lines in California and other places, are in reality large scale experiments which, if unsuccessful, will cause heavy losses to fall upon those who have been financing these undertakings.

In order to obtain independent and reliable figures concerning the effects of exposure upon aluminium, the

[1] *Comptes Rendus*, March–April, 1899.

writer, since October, 1899, has been carrying out two series of observations in the North of England. The samples of aluminium used are in rod and wire form, and were kindly placed in the writer's hands by Messrs. T. Bolton & Sons, of Oakamore Wire Works, and by the British Aluminium Company. In order to make the investigation more complete, the inquiry was extended to all metals and alloys used for electrical conductors, and samples of copper, tinned copper, and of galvanised iron wire were also sent to the writer by Messrs. T. Bolton & Sons. It is a curious fact that there would appear to have been no previous scientific observations upon the durability of these metals or alloys under atmospheric exposure; and the choice of the 'metal or alloy for overhead wires in any particular district has apparently been settled by custom rather than by scientific knowledge.

The methods of observation adopted by the writer in his experiments were as follows :—

The rods and wire were cut into 2-feet lengths, and were mounted upon glass insulators in two frames, so that their position was parallel one to the other, and horizontal with regard to the ground.

Fig. 1 is a reproduction of a photograph of one of these frames containing the sample wires. The frames carrying the wires were so placed that the drops of water collecting upon the wires in wet weather could not by any chance pass from one wire to another, and thus bring electrolytic action into play. Each length of wire was carefully marked and weighed before commencing the exposure, and the weights recorded. The one frame with its nine insulated sample wires was exposed upon the roof of a building in St. Helens, Lancashire, from October 11th, 1899 to August 23rd, 1900; and the second frame was similarly exposed at Waterloo, Lancashire, for the same period of ten months.

The climate of St. Helens is probably too well known to need description; but it has improved considerably in recent years, owing to the closing of several chemical works. The place in which the wires were exposed is now singularly free from chlorine and hydrochloric acid gases.

Waterloo is on the Mersey, six miles north of Liverpool, and its atmosphere is that of an ordinary west-country seaside town, *plus* much sand. During the exposure period

of ten months the frames were not touched or moved. At the end of this period the wires were removed from the frames, cleaned from the soot and dirt of all kinds which had accumulated upon them, and after thoroughly air-drying, were re-weighed. The results are set forth in Table II.

TABLE II.

Results of Exposure Tests of Aluminium and other Wires.

Composition and Form of Sample.	Waterloo Set; 10 Months.		St. Helens Set; 10 Months.	
	+ = Gain, − = Loss, in Weight.	Remarks.	+ = Gain, − = Loss, in Weight.	Remarks.
	Per cent.		Per cent.	
Aluminium Rod No. 1	nil	These 5 samples were all pitted, especially on the under sides, where water-drops had collected and dried.	+ ·27	These 5 samples were very badly pitted. Dirt had settled in their corrosions and could not be removed by scrubbing.
„ „ No. 2	+ ·13		+ ·51	
Aluminium Wire No. 1......	+ ·41		+ ·83	
„ „ No. 2......	nil		+ ·83	
„ „ No. 3......	+ ·55		+ ·54	
Galvanised Iron Wire No. 1	− ·15	No change in appearance to the eye.	− 1·44	Badly corroded. Zinc partly eaten away.
„ „ No. 2	− ·16		− 2·13	
Copper Wire No. 1	nil	Oxidised on surface, but not pitted or corroded.	− 1·65	These wires were perfectly black, and could not be distinguished.
Tinned Copper Wire No. 1	nil		− 1·31	

The above figures show that the aluminium wires and rods had nearly all gained in weight during the ten months' exposure, the gain varying from nil up to ·83 per cent. on the weight of the original wire. This gain must be attributed to the corrosion of the rods and wires, and to the settling of soot and dirt in the crevices. No amount of scrubbing would remove this dirt. The weights of these aluminium rods and wires were therefore of very little use in determining how far they had suffered by the exposure, and the two samples of aluminium wire marked No. 1 in Table II. were submitted to conductivity, and tensile strength, tests.[1] The results are given in Table III.

[1] These tests were made by the Faraday House Testing Institution.

TABLE III.

TESTS OF ALUMINIUM WIRE FOR CONDUCTIVITY AND TENSILE STRENGTH.

	Conductivity; Copper 100.	Tensile Strength; tons per square inch.
Original wire	51·3	13–16[1]
Waterloo sample	51·4	12·06
St. Helens sample	46·6	11·15

It has been customary to assume that the aluminium wire supplied for electrical purposes had a conductivity of from 57–63 per cent. that of copper, taking equal sectional areas of the two metals. The following figures were in fact sent to the writer with the samples of aluminium wire used in some of these experiments.

Sample Wire.	Composition.	Conductivity; Copper 100.	Tensile Strength; tons per square inch.
1. Rod	98·99½ per cent. Al.	60–62	16–18 tons
2. Wire	99 per cent. Al.	65	13–16 tons
3. Wire	99 per cent. Al. 1 per cent. Fe.	62	16–18 tons

Samples 2 and 3 were, however, submitted to independent tests for conductivity, before exposing, and it was found that in place of conductivities of 65 and 62 per cent., they only possessed conductivities of 51 per cent. and 54 per cent. respectively. It is, of course, known that pure aluminium has a conductivity 63 per cent. that of copper; and the low conductivity of these samples can only be explained by the presence of iron, or other metals, introduced to increase their strength. The conductivity tests supplied by the firm in question were evidently based on surmise, not on actual results.

The tests given in Table III. show that although the St.

[1] This test was supplied by the firm from whom the wire was obtained, and it is therefore not strictly comparable with the others.

Helens wire had gained in weight, yet considerable loss in conductivity and tensile strength had resulted from the exposure and consequent pittings. The Waterloo samples, although pitted to a less extent, had not lost in conductivity; and the tensile strength had probably not suffered, although in the absence of a special test of the original wire it is impossible to be quite certain on this point. The remains of these two sample wires are here on the table for examination by those interested in the subject, and photographs of the more badly corroded wire are also exhibited.

Examining Table II. again, in order to study the results obtained with the remaining wires, we see that both in Waterloo and in St. Helens the galvanised iron wires had lost in weight; the losses in the latter case being serious and amounting to 1·44 per cent. and 2·13 per cent. of the original weight of the wires. In this case almost the whole of the zinc had been dissolved away by the action of the acid gases, and the exposed iron was badly oxidised. The two Waterloo samples were, on the other hand, bright and clean, and to the eye did not appear to have suffered.

The copper and tinned copper wires exposed at Waterloo were oxidised on the surface; but no pitting had occurred, and there was neither loss nor gain in weight. The two samples of similar wire exposed at St. Helens had both lost in weight (1·65 and 1·31 per cent. respectively), and as the whole of the tin had been dissolved off the tinned copper wire, it was impossible to distinguish one from the other.

V. Conclusions.

It is perhaps unwise to found any general conclusions upon the results of these observations, since they refer to two districts only. The British Isles can afford a very wide and ample selection in the way of climates. It would, of course, be interesting to have similar series of observations established in London, and in one or more of our large cities with a manufacturing population—say Manchester, Glasgow, or Sheffield; but at the moment the writer is unable to establish these. The investigation, however, proves that the aluminium wires at present sold for conducting purposes in this country are not perfectly resistent to atmospheric corrosion, and that in the atmosphere of a town

where sulphurous acid gas exists as an impurity in the air the metal is very badly attacked.

Though St. Helens is certainly an exceptional town, it is probable that in any large town burning a large amount of coal, either for domestic or for manufacturing purposes, the atmospheric conditions will approach those obtaining there, and that the various metals will be attacked to a somewhat similar degree.

Under such conditions all metals used for overhead conductors are subject to attack, and aluminium is unsuitable for use, owing to the pitting which occurs. In such towns it is advisable to use copper for all overhead wires, and the proposal to use aluminium, *especially for overhead trolley lines*, must be condemned.

In country districts or in small towns, where the impurities present in the air are reduced to a minimum, all metals experimented with seem to be fairly durable, but the slight pitting of aluminium which occurs—even in such an atmosphere, may prove serious; for by allowing the lodgment of small particles of foreign matter it may in time lead to the disintegration of the whole mass of metal.

Upon this point the researches of Ditte, already alluded to, are of importance.

The observations are being continued at the two localities named, and on a future occasion the author hopes he may have the pleasure of presenting further figures on this subject for your consideration.

The PRESIDENT: I have a communication here, which is, I believe, the very first communication that the Director of the National Physical Laboratory, Dr. R. T. Glazebrook, has sent to any meeting like this:—

"THE NATIONAL PHYSICAL LABORATORY,
"OLD DEER PARK,
"RICHMOND, SURREY,
"*January* 9, 1901.

"DEAR SIR,

"I had hoped to have been present at the meeting of the Institution to-morrow night, but fear I shall be unable to come. It occurred to me on reading Mr. Kershaw's paper that it might be thought desirable to repeat and extend his very interesting observations on the relative durability of aluminium and other metals for certain electrical purposes. If this is the case, I shall be glad to endeavour to

arrange to have such experiments carried out at the Natural Physical Laboratory, and shall welcome the advice and assistance of any members of the Institution interested in the matter.

"Yours truly,

"R. T. GLAZEBROOK."

I believe I have heard that Lord Kelvin is making pretty large experiments on this subject, and that he has spread some aluminium wires to find out their durability somewhere in Scotland—at Foyers, I believe.

Mr. J. GAVEY: The Post Office has, for about twelve months, had under consideration the desirability of carrying out certain experiments with aluminium wire, and the reason why they were deferred for such a long period was the difficulty in obtaining a suitable soldered joint. Old telegraph engineers, whose memories carry them back to the period before the invention of the Britannic joint, have a great horror of unsoldered joints; and before we undertook to carry out experiments we deferred our trials, at all events until something in the nature of a satisfactory soldered joint could be obtained. The question of soldering seemed to be solved so far as the mere soldering of joints was concerned, but unfortunately the heat that was necessary for the soldering annealed the wire and reduced its strength by exactly 50 per cent. Ultimately, not to delay the experiments any longer, we arranged to run out the wires in the full length of the coil, to erect each coil of wire on an insulator, and to solder the joint in a little loop, so that the annealing of the wire itself had no injurious effect on the strength of the portion that was suspended. We have now obtained something like 18 or 20 miles, and about 15 miles of this wire were erected in the Potteries, near Hanley. We thought that was a very suitable place to expose it for a crucial trial. The wire handled very well, but our first experiment has not been very promising. We erected 15 miles of the wire early in December, and within about a fortnight of that time a heavy gale of wind blew across the country, and there were about eight or ten breaks in these spans that were erected. The wire that was put up weighs 75 lbs. to the mile; its approximate diameter is 1·24 millimetres; its breaking strain was 340 lbs., which, being reduced to tons per square inch, came out at 12·568 tons; it stood ten twists in three inches; its maximum resistance per mile was 6·158 ohms, and its specific resistance came out at 2·974 ohms. I do not want to make too much of this, and it is perhaps a little too early to come to any conclusion on the subject, beyond, perhaps, this: that it is quite possible that, either in the preparation of the billets or in the rolling or drawing of the wires, there were places which were either very crystalline or which differed in character from the remainder of the wire. I think, carrying back our experience to the original use of hard-drawn copper wire for telegraph and telephone circuits, we met with considerable difficulties in obtaining exactly the quality of wire that we asked for. It was very difficult, in the first place, to meet the rather stringent specifications of the Post Mr. Gavey.

Mr. Gavey.

Office, but our English manufacturers—and I am glad to say this, after all the obloquy that has been heaped upon them—came to the front, and, after considerable expenditure, they did succeed in meeting our requirements. No doubt in the manufacture of aluminium wire, when a little more experience has been obtained, similar success will attend the efforts of manufacturers. You may take it for what it is worth, that the first trials have not been quite so satisfactory as we hoped for. I should have added, perhaps, reference having been made to San Francisco, or rather to California, that I had the pleasure of a conversation with Mr. Sabine, the President of the Pacific Telephone and Telegraph Company, about six months ago. He had erected a considerable length of aluminium wire for telephonic purposes, and he told me that the line had been subjected to breaks of a somewhat similar character to those that we have experienced, and for which they could not exactly account.

Mr. Swinburne.

Mr. SWINBURNE: In this paper there is one very important point which is not very fully dealt with, and that is the question of the purity of the aluminium. A very small portion of any foreign metal in aluminium will probably lower the conductivity, and therefore throw the price-ratio wrong; that is to say, a very little further purification of the aluminium will probably make its current-carrying power greater, so that the price-comparison is altered. A very little further purification will also probably prevent the corrosion. The three chief impurities in aluminium are sodium, which is about the worst element you possibly can have, from the corrosion point of view; silicon, which probably also gives rise to corrosion; and iron, which perhaps does not matter, except as to resistance. The manufacturers of aluminium are continually improving it, and therefore there is considerable hope in that direction. But the next difficulty, which Mr. Gavey has also mentioned, was the question of soldering. Nearly all the aluminium alloys are unstable if they have much aluminium; that is to say, the aluminium alloys with a lot of the other metal and a little aluminium are generally good; also with a lot of aluminium and a little of the other metal they are generally good. But the aluminium alloys with about equal proportions of one metal and aluminium are very curious; they are nearly always unstable, and very many of them tumble to powder without being touched. It is quite easy to solder aluminium, but the solder does not necessarily last more than two or three months, which is a most annoying thing. It has struck me—I have been told that I am wrong, but I have never been told why—that there is a practical difficulty if you use a solder that is not nearly all aluminium, because if you use any other solder there must be a surface cutting the joint somewhere that is in the unstable condition, and that surface is probably what breaks. Mr. Kershaw says that he thinks aluminium is hopeless for insulated conductors. I do not think that is altogether so. It rather bears, perhaps, on the next paper, but it may be interesting to point out what I mean now. Aluminium is chiefly used for overhead conductors. When you get a very high pressure on an overhead conductor, you must remember that the slope of the potential varies as the distance from the centre, so that it is very great just near the surface of the

metal, and the higher the potential and the smaller the lead the greater the fall. The result is that when you get up above 20,000 or 30,000 volts with a small conductor, if you look at it in the dark you will see discharges going on all over it. The air is breaking down, and is getting, as it were, torn. That means waste of power, and these leaks for very high pressures become very serious. Therefore aluminium is better than copper, unless you make the copper into a tube. It is probable that it will be cheaper to use, considering how near they are in price, a big aluminium wire than a copper tube. The same thing comes in when you are dealing with insulated conductors for high pressures. It may quite happen with a large power-transmission that either a copper tube must be used for the central, or else aluminium; and in that case you have no further chance of corrosion. It is quite possible that aluminium may be exceedingly important, even in covered conductors, in large engineering schemes. Mr. Swinburne.

Professor GEORGE FORBES (*communicated*): In reference to Mr. Kershaw's paper on the use of aluminium as an electric conductor, I beg to quote the following passage from a letter written to me by the vice-president and treasurer of the Niagara Falls Power Company, and dated Niagara Falls, N.Y., December 29, 1900: "We are building our second line to Buffalo with aluminium cables, and shall furnish 5,000 H.P. to the Pan-American Exposition beginning April 1st." Professor Forbes.

In the same connection I may mention that I have had exposed at Fettercairn, Kincardineshire, two aluminium conductors, each ¼ inch diameter and 200 yards long, one for eighteen months and the other nearly three years—the one being of aluminium from Neuhausen, the other from Foyers. Both of these are in a perfectly good condition.

Mr. E. RISTORI (*communicated*): The Company in which I am interested is, of course, quite as anxious as any one else to prove conclusively whether aluminium can advantageously be adopted as an electrical conductor, and on this point we may remark that during the last three or four years, the Company has had several miles of aluminium wire and strip working for telephone, lighting, and power transmission purposes at Foyers, and that up to the present, we have not had any trouble with these installations, either electrically, on account of the conductivity being lower than that calculated for, or mechanically, from breakdowns due to the weather, which is not of the best in that locality. Moreover, I should mention that this plant was not erected in the nature of an experiment, as we were already convinced of the suitability of aluminium for the purposes required, but for permanent and heavy work, and, as I say, the results have been in every way satisfactory. The metal used was that which we are turning out at our factory, and I am arranging some experiments with a view to ascertaining the present conductivity of some of these wires, which have now been in use for several years, and I hope to communicate the results to the Institution later. Mr. Ristori.

The figures given in Mr. Kershaw's paper representing the conductivity of his specimens as being between 51 per cent. and 54 per cent. that of copper, I must say are very much below those obtained

Mr. Ristori.

for commercially pure aluminium, such as is being produced at the present time, which show that it has a conductivity of from 60 per cent. to 65 per cent, as compared with copper of equal section. We have no doubts upon this point, which has been confirmed by experiments executed under Lord Kelvin, and by the well-known firm of Messrs. Thomas Bolton & Sons, and others.

Of course Mr. Kershaw does not say anything as to the analysis of the wires he experimented with, which materially lessens the value of his results. We have also remarked that, in the case of one of the wires he tested, the conductivity of the aluminium was slightly greater after ten months' exposure to the atmosphere of a manufacturing town than it was at the beginning of the experiment, which certainly seems to show that the metal was not affected injuriously.

In conclusion, the point which we wish to maintain, and are also prepared to prove, is that aluminium averaging 98½ per cent. to 99½ per cent. purity, has a conductivity of from 62 per cent. to 65 per cent. that of copper, and that this conductivity is not appreciably affected by exposure to the atmosphere whether of town or country.

On the whole, therefore, we consider that Mr. Kershaw's paper, besides tending to do harm to this industry, is also misleading in its results, so that we are anxious to put the matter in its true light.

Mr. Gibbings.

Mr. W. GIBBINGS (*communicated*): I have read this paper with much pleasure, as the subject is one of growing interest to both engineers and metallurgists, and one which will doubtless occupy the attention of both very considerably in the near future. Despite the enormous reduction in the cost of producing aluminium, concurrently with the enhanced price of copper, it is evident from the data supplied by the author of the paper that the difference in prime cost alone, precludes the use of aluminium for bare conductors. For covered conductors, the use of the metal is quite hopeless. Taking the price of ordinary gauge copper wire at £91 per ton, 100 per cent. conductivity, and the conductivity of aluminium at 52½ (as found by Mr. Kershaw), the maximum price at which the latter metal could compete with its rival would be

$$\frac{S \times P \times c}{s \times X \times C} = £159.$$

Should, however, the price of aluminium fall to this, its physical properties still render it an undesirable substitute for copper. It is certain that, at least in vitiated atmospheres, the corrosion which takes place is considerable. This is shown by the sample tested at St. Helens, which, although fairly constant in weight, lost during the trial 4·7 in conductivity, a clear indication of corrosion and waste. On the other hand, although the data given by the author relating to the copper wire is not conclusive (in the absence of conductivity tests of these wires after exposure), yet the small loss in weight on the wires experimented on at St. Helens would seem to imply less corrosion than was suffered by the aluminium wires.

With either metal I should expect the corrosion and waste to be greater on first exposure, as the dirt accumulated and the oxide formed

would probably protect the wires to some extent after long use. All these points can only be determined by a lengthened exposure and frequent tests. Mr. Gibbings.

Tinning copper wire intended for use in a bad atmosphere, especially near chemical works, is apparently a waste. This is only what might be expected, seeing that there is always present in the atmosphere of such localities hydrochloric acid and free chlorine.

In comparing the relative value of copper and aluminium for electrical conductors, it should not be overlooked that, whilst the conductivity of aluminium has a downward tendency, due to the necessity of using a strengthening alloy, the conductivity of copper is increasing by improved methods of manufacture. My company is now delivering as a regular thing copper of 101 per cent., and occasionally 102 per cent. is reached. The tensile strength is also increasing, and is now considerably above the requirements demanded by the Post Office specification.

With aluminium, the use of mechanical joints, which appear to be the most satisfactory, must, on long lines, materially affect the resistance of such line.

Mr. Kershaw, in reply (*communicated*): I am gratified to learn from Professor Glazebrook's letter to the President of this Institution that he considers the question of the corrosion of aluminium and other wires under atmospheric exposure of sufficient importance to warrant the commencement of exposure tests at the new National Physical Laboratory at Kew. Mr. Kershaw.

I have stated in my paper that it would be interesting to have a series of observations carried out in different localities, and, I therefore, hail Professor Glazebrook's offer with satisfaction. It will be instructive to compare the results obtained at Kew, with the commercial samples of wire, with those I have obtained in Lancashire.

With regard to the President's statement that Lord Kelvin is carrying out some exposure tests with aluminium conductors in the North, I may say that I was not aware of this fact. Professor Forbes has, however, instituted some practical tests of this character in Scotland, and possibly these are the observations to which Professor Perry alludes.

Mr. Gavey, to whom I am much obliged for his information concerning the Post Office trials of aluminium, has referred to the difficulty met with in making satisfactory joints with the new metal. I suppose Mr. Gavey is aware that in America a mechanical sleeve-joint is generally adopted, and that it is giving most satisfactory results. A new method of "autogenous soldering"—or welding—has also recently been brought out and patented by Heraeus of Hanau, and at the Paris Exhibition a wire 5 feet long, made up of twelve separate pieces joined together by this method, attracted much attention. The method is fully described by the inventor in the "Zeits. f. Angew. Chemie" of July 24, 1900. The difficulty of jointing aluminium is, therefore, practically surmounted.

Mr. Swinburne in his remarks has pointed out that I have been incorrect in stating that there is no future for aluminium as an insulated

Mr. Kershaw.

conductor. In my remarks upon this point I was referring of course solely to the greater surface area of conductors of the light metal, and I am ready to bow to Mr. Swinburne's superior knowledge, and to accept his statement that the cost of insulating aluminium for *high tension currents* will be less than in the case of copper.

With regard to the influence of small amounts of impurity upon the conductivity of aluminium wires, I am aware of the importance of this aspect of the subject.

My experiments were, however, directed towards finding the durability of the metal now sold for conducting purposes, and it would not have been of any practical value to confine my experiments to specially prepared and purified forms of aluminium.

I have given in my paper the "official" descriptions of three of the samples used in the experiments. The discrepancy in the conductivity tests has, however, caused me to doubt the value of these "official" descriptions; and before the results of the further observations with the wires exposed at St. Helens and Waterloo are published, I shall hope to have completed independent analyses of the various metals and alloys used in these experiments.

[*Communicated March* 15, 1901]: Mr. Ristori in his communicated remarks has thought it necessary to impugn the accuracy of the conductivity tests published in my paper. It would, however, have been more to the point if Mr. Ristori, in place of quoting general tests, had given the *actual* conductivity tests of the wire, samples of which were supplied by his firm to me in 1899. Personally I have little doubt as to the correctness of the tests given in my paper, and confirmation from an independent source will be found in the issue of the *Electrical Review* for March 8, 1901. In a report upon the condition of the aluminium wires erected at Northallerton in 1899, it is stated that the original electrical conductivity of the wire was only 51 per cent. This would seem to indicate that the wire sold by the British Aluminium Company in 1899, for electrical purposes, was far below the 60–65 per cent. conductivity standard referred to by Mr. Ristori; and some of the samples placed in my hands by the British Aluminium Company in that year were evidently similar in composition to the wire erected at Northallerton.

In conclusion I may state that my interest in the subject is purely scientific, and that I am only desirous of arriving at a true estimate of the future that awaits "aluminium" in this new field of usefulness.

The President.

The PRESIDENT: I will ask you to give your thanks to Mr. Kershaw for this valuable paper.

The resolution was carried by acclamation.

The following paper was then read:—

CAPACITY IN ALTERNATE CURRENT WORKING.

By W. M. MORDEY, Member of Council.

This is an attempt to consider some of the effects of electro-static capacity in insulated cables for alternate current working, especially as regards the power and plant.

Distinctions formerly drawn between "current electricity" and "static electricity" have left impressions on our minds by no means helpful now. When we come to deal with electro-static capacity in engineering applications with rapidly alternating currents, we find that so far from being "static" the conditions and effects are those of current or flow, and may most usefully be studied as such.

Electro-static capacity in cables in some respects is an advantage, but on the whole it is a serious drawback in alternate current work, mainly because it is directly and indirectly a cause of waste of power.

Now that many applications of extra high tension alternate current distribution are being promoted, it may be useful to carefully examine what is involved in this property as regards the power and plant required.

In attempting to do this I may be allowed to begin at the beginning, as I think this may be useful to many engineers who have not hitherto considered the subject in its relation to economy of working.

The capacity of a cable is measured usually by comparing it with that of a standard condenser, using a low pressure and observing the throw of a ballistic galvanometer.

The unit of capacity is the farad, but as it is too large for practical purposes, the practical unit adopted is the microfarad or $\frac{1}{1,000,000}$ of a farad.

Electric supply cables have a capacity varying from about one-fifth of a microfarad to about one microfarad per mile, according to the size, the form, and the kind of insulating material used.

If two cables are connected to the terminals of an alternator, a current to charge the cables will flow into them as the pressure rises in each half period, and back again as the pressure falls. As this occurs usually from 100 to 200 times a second it is of course just as "continuous" as any other alternating current. The amount of this charging current is easily found if we know the capacity of the cable.

Perhaps I may be allowed to give a practical idea of what a microfarad is, in terms of volts, amperes, and periods.

The capacity current in amperes

$$= \frac{\text{volts} \times \text{periods per second} \times \text{microfarads} \times 2\pi}{1,000,000}.$$

Take an illustration from ordinary familiar working conditions in order to fix in the mind a quantitative idea of this :—

One microfarad takes 0·6283 *amperes at* 2,000 *volts* 50 ∿.

The above expression assumes that the capacity is independent of the pressure.

In order to satisfy myself on this point I was able, by the kindness of Mr. Gray and the Silvertown Company, to make some tests on some rubber cable in the tanks at the Silvertown Works. The alternator ran at 90 ∿, and the pressure was varied from 2,000 to 5,000 volts. The following readings were obtained :—

Volts.	Amperes.
2,000	0·62
2,500	0·75
3,000	0·97
3,500	1·11
4,000	1·29
4,500	1·45
5,000	1·65

These results which are plotted in Fig. 1 show that the current is simply proportional to the pressure, and therefore that the capacity is not affected by the pressure.

I may here draw attention to the ease with which capacity measurements of systems of mains may be taken. It is a measurement that is, I think, never taken by station engineers.

Knowing the E.M.F. and the periodicity, it is only necessary to take the current. Then

$$\frac{\text{Volts} \times \sim \times 2\pi}{\text{Amperes} \times 1,000,000} = \text{microfarads}.$$

If the tests are always taken at one E.M.F. and periodicity, the scale of the ammeter may be marked to read directly in microfarads. This method is of course merely according to the "Ohms law" of the subject, but it does not appear among those given in standard works on the subject.

As it can be applied wherever an alternator is available, it should be useful to station engineers and others, especially for taking the capacity after the mains have been laid. The

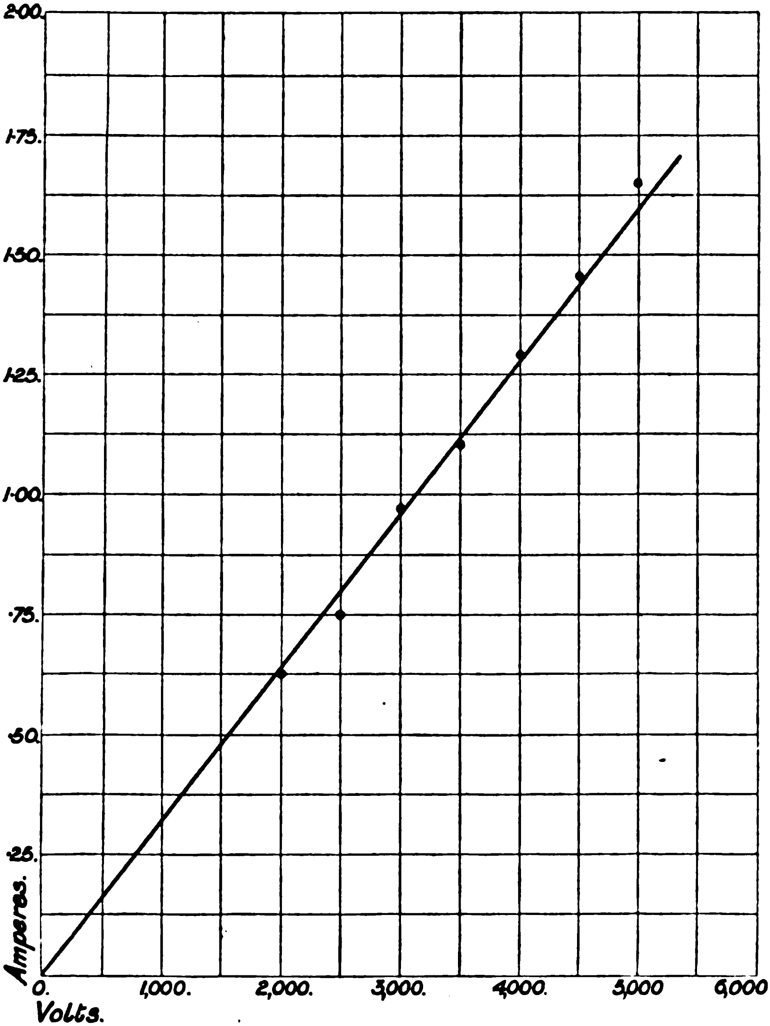


FIG. 1.—Capacity Current taken by Cable at Various E.M.F.'s, 50 ∿.

test can be made at the full working pressure—and variations of capacity with age may be easily observed.[1]

In order to show what the capacity current may amount

[1] Since reading this paper I have found this method useful only with true sine curve alternators—see discussion, p. 396.—W. M. M.

to in practice, I have worked out the following table for a length of cable having a capacity of one microfarad.

The capacity current is directly proportional to the pressure and to the periodicity.

The "apparent watts," or the amperes multiplied by the volts, are proportional to the square of the pressure for any given periodicity.

The table gives the current taken at various pressures by a cable of 1 microfarad at 50 ∿, also the apparent watts taken and the apparent H.P. Another column, to be referred to later, gives the true watts.

TABLE I.

CAPACITY LOSSES IN CABLES.

Capacity Current, Apparent Energy, and Actual Energy required by a Cable of 1 microfarad at various E.M.F.'s, 50 ∿.

Volts.	Amperes.	*Apparent Watts.* V × A	*Apparent E.H.P.*	True Watts. V × A × ·124.
1,000	0·314	314	0·42	39
2,000	0·628	1,256	1·69	156
3,000	0·942	2,826	3·8	350
4,000	1·256	5,024	6·7	623
5,000	1·57	7,850	10·5	973
6,000	1·88	11,300	15·	1,400
7,000	2·2	15,400	20	1,910
8,000	2·5	20,100	27	2,490
9,000	2·83	25,430	34	3,150
10,000	3·14	31,400	42	3,890
15,000	4·71	70,700	95	8,760
20,000	6·28	125,600	166	15,570
25,000	7·85	196,000	263	24,300
30,000	9·42	282,600	380	35,040
35,000	11·	385,000	516	47,730
40,000	12·56	502,400	672	62,300

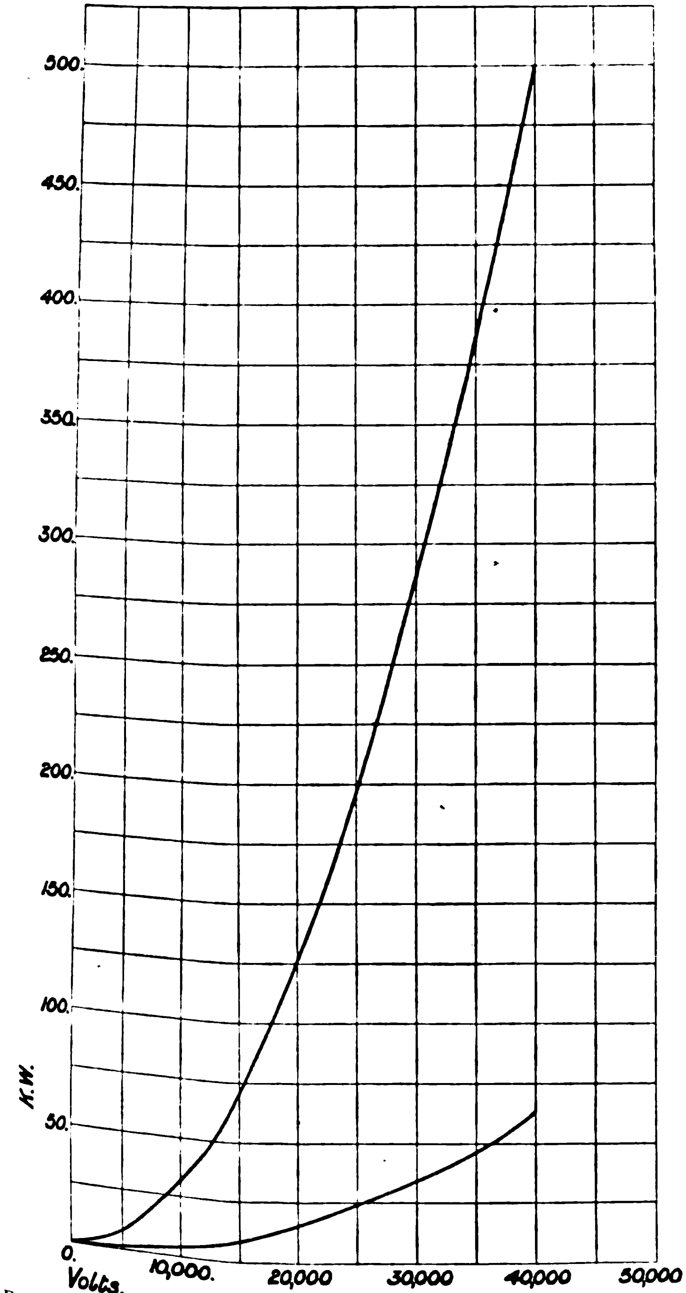


FIG. 2.—Apparent and Real K.W. taken by Cable of 1 mfd. at various E.M.F.'s.

50 ∿.

Upper Curve = Apparent K.W.
Lower „ = Real K.W.

Fig. 2 is plotted from this table, the upper curve giving the apparent power, and the lower curve the true power. Fig. 3 is the lower part of Fig. 2 drawn to a larger scale.

At 100 ∿ the current and watts would be double, and at 25 ∿ they would be one-half of the values given in the table.

When it is remembered that large distribution systems working at 10,000 to 20,000 volts may, and probably often will, have cables the capacity of which may be scores of microfarads, it will be realised that the magnitude of the capacity effect is considerable. Even at low and moderate pressures it is by no means negligible.

The term "apparent watts" is rather unsatisfactory. It is generally used to indicate that the whole of some volt-ampere quantity is not true watts, but it is sometimes applied to volt-amperes that are not watts at all. For instance, people will say, "So many true watts and so many apparent watts." The safest plan seems to be to use the term "apparent watts" as including both true and false watts, adding the power-factor, when known, to show how many of the apparent watts are true and how many are false.

The next question to consider is, What is the power-factor of the cables? This is very important, for whatever we may be able to accomplish in neutralising or compensating the charging current, so far as I know we can do nothing to reduce the true watts absorbed by the dielectric of any given cable at any given pressure and periodicity. These true watts are made up of ordinary copper loss or C^2R due to any charging current flowing in the conductor, to leakage, and to dielectric hysteresis.

The C^2R loss due to the passage of the capacity current is usually unimportant, at least in large cables. It is easily calculated.

The leakage is also usually unimportant. Thus if a 2,000-volt cable has an insulation resistance of say 1,000 megohms per mile, the leakage will be only 2 millionths of an ampere and 4 thousandths of a watt per mile.

Then there is the loss from dielectric hysteresis; that is, the loss of energy due to the insulating material being subjected to rapidly repeated and violent electric strains.

Whether this effect is simply due to mechanical friction caused by rapidly repeated attractions and repulsions

between the particles of the insulating material, and between that material and the metal within it and outside of

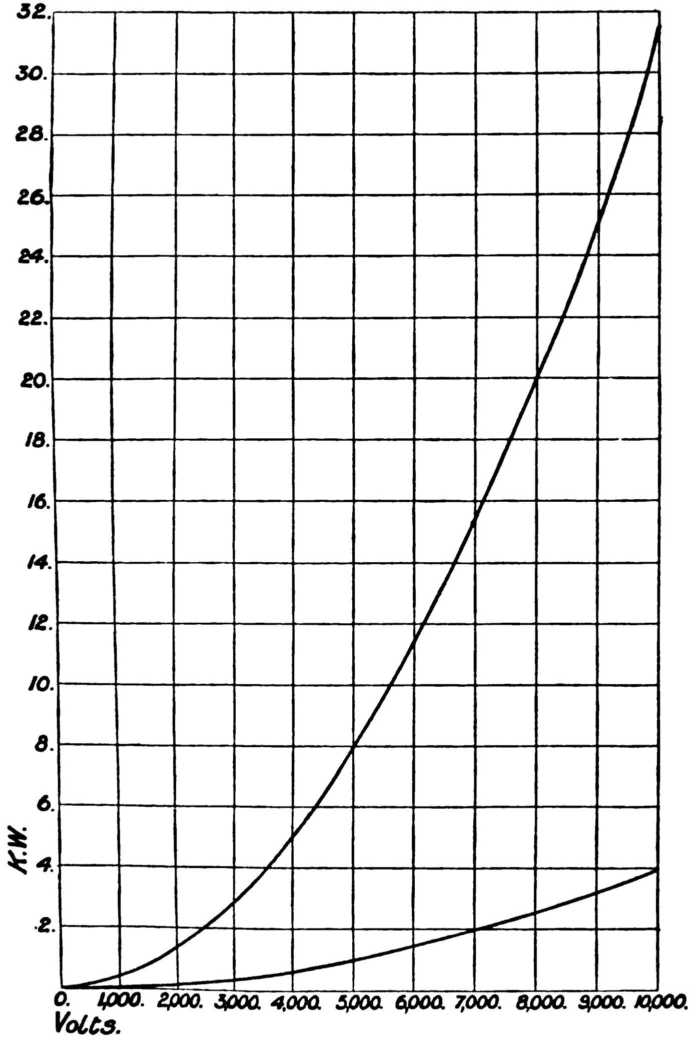


FIG. 3.—(This is the lower part of Fig. 2 drawn to a larger scale.)
Upper Curve = Apparent K.W.
Lower " = Real K.W.

it; or whether it is due to some more obscure molecular or polarisation effect, I do not know. A simple explanation is to be preferred if a satisfactory one can be got.

From what we can observe of actual mechanical vibration it seems possible that the first-mentioned cause is sufficient to account for the loss.

But how much is this loss ?

By the kindness of Mr. Sparks and the County Company I have been enabled to make some tests on this and other points.

The cable placed at my disposal was $5\frac{1}{2}$ miles of 37/15s concentric rubber covered. It was steel sheathed, drawn into 2-in. cast-iron pipe—the outer conductor was earthed, and the steel sheathing also earthed every 220 yards by stranded copper cables bolted to the iron pipe.

This cable was intended to be used at 6,000 volts 50 ∿, but my test was made at 2,050 volts 100 ∿.

The makers' test gave the capacity as follows:—

·86 microfarad between inner and outer, and
1·06 „ „ outer and earth.

As the outer was earthed, I need only consider the inner. The capacity current should be

$$\frac{2{,}050 \times 100 \times \cdot 86 \times 5\cdot 5 \times 2\pi}{1{,}000{,}000} = 6\cdot 092 \text{ amperes.}$$

I found the actual current was 6 amperes—practically confirming the makers' test. It was interesting to find a measurement made at a high E.M.F. and high periodicity gave the same result as a ballistic galvanometer test with a low E.M.F. The cable was run for several hours with a Thomson Recording wattmeter in circuit, this instrument having been specially tested by the County Company at low power-factors. The pressure was nearly steady at an average of 2,040 volts, the current being 6 amperes. The apparent watts were therefore 6 × 2,040 = 12,240.

The true watts, by the wattmeter, were 1,515, or 275 watts per mile.

The power-factor $= \frac{1{,}515}{12{,}240} = 0\cdot 124$; that is to say, the true watts were 12·4 per cent., or about $\frac{1}{8}$th of the apparent watts.

The C^2R* and the leakage were both negligible, so the whole of this loss was due to dielectric hysteresis.

* The C^2R in this case = 13·4 watts.

It cannot be said that 2,226 apparent watts and 275 true watts per mile are negligible quantities. This is at 2,000 v. 100 $\sim$.

When the cable is worked as intended at 6,000 volts 50 $\sim$ the losses per mile will be—

$$\cdot 86 \times \cdot 6283 \times 3 = 1 \cdot 621 \text{ amperes.}$$

The apparent watts per mile $1 \cdot 621 \times 6{,}000 = 9{,}726$: and the true watts $9{,}726 \times \cdot 124 = 1{,}206$ per mile.

This of course is on the assumption that the power-factor is the same at high pressures as at low (as seems probable), and that the loss in this instance was accurately determined.

The dielectric loss is not preventible. It may be lessened by increasing the thickness of the dielectric—that is, by reducing the strain—or by using a dielectric of low specific capacity, and by working at a low periodicity; but for any given case it must be accepted as one of the conditions of working. In some respects it is like the hysteresis loss accompanying the magnetising and demagnetising of iron.

But dielectric hysteresis seems to differ from magnetic hysteresis in showing no saturation effect. Possibly at very high pressures the curve may begin to bend down, but I should expect the insulation to break down earlier than the proportional law.

I have already said that the actual loss in the dielectric, whatever its amount, is going on always when the mains are energised—whether any power is being transmitted or not. In the case just examined of the 6,000-volt 50 $\sim$ transmission it amounts to about 0·23 watt per foot of cable. So far as it is a cause of waste of power this may be, and often is, a much more important loss than the ordinary C^2R copper loss. This will be seen from the following comparison:—

The 37/15s cable (0·154 sq. in.) has a resistance of 0·271 ohm per mile, or 0·542 per mile for the two conductors. The constant dielectric loss of 1,206 watts per mile is therefore equivalent to a copper loss due to the constant passage through both conductors of 47·2 amperes, or at the current density of 326 amperes per square inch; or a current that would give a drop of 25·6 volts per mile (or in the single

conductor 67 amperes = 460 amperes per sq. in.), or 0·46 per cent. per mile on a 6,000-volt circuit. If the cable is in continuous use its dielectric uses up 10,564 B.T. units per mile per annum.

To further illustrate this loss I have worked out tables for 2,000 volts and 7,500 volts, taking five commercial sizes of concentric cables and giving the dielectric losses, and the copper losses that would be equivalent to those dielectric losses. I have taken the dielectric power-factor as 0·124 as before. This factor may, of course, vary with different cables.

TABLE II.

Cables working at 2,000 volts, 50 ∿

LOSSES IN DIELECTRIC PER MILE.

Size of Cable		7/20	19/20	19/16	19/14	37/16
Copper Section: sq. in.		·007	·019	·060	·094	·118
Resistance		6	2·213	·7	·45	·36
Capacity, mfd.		·33	·5	·6	·7	·75
Apparent Watts... ...		419	628	754	880	944
True Watts...		52	78	93	109	117
Current (and current density) in conductor that would give loss equivalent to that in dielectric	Amp.	2·95	5·95	11·55	15·6	18
	Amp. per sq. in.	420	312	192	165	153
B.T Units per Mile per Year		455	683	815	955	1,025

Table III.

Cables working at 7,500 volts, 50 ∿.

Losses in Dielectric per Mile.

Size of Cable		17/20	19/20	19/16	19/14	37/16
Mfd. per Mile		·2	·33	·364	·425	·454
Apparent Watts... ...		3,300	5,450	6,000	7,000	7,500
True Watts...		410	670	744	870	930
Current (and current density) in conductor that would give loss equivalent to that in dielectric	Amp.	8·3	17·4	32·6	44	50·7
	Amp. per sq. in.	1,180	913	540	467	430
B.T. Units per mile per mile		3,590	5,870	6,520	7,630	8,147

Note.—In these two tables the equivalent copper loss is taken as that in a single conductor—not in a "lead and return"—for the reason that the dielectric loss is the same (for the same capacity) whether the main is a single one or double.

Take a higher pressure illustration. Imagine a system of 40 miles of cable working at 20,000 volts 50 ∿, the capacity being 0·5 mfd. per mile. With no load and no apparatus connected to the mains the generator would have to provide at charging current of 125·6 amperes at 20,000 volts,

= 2,512,000 apparent watts.

If the power-factor is ·124, then the actual energy absorbed by the mains will be 311,488 watts, and the number of B.T. units consumed per year will be 2,728,633, or an annual output that is exceeded by only a very few electric supply stations in this country. The loss works out at 1·5 watts per foot of the cable with this power-factor.

One rather unfortunate property of cables is shown by these tables. I refer to the fact that as different sizes of cables, made systematically to be suitable for safely working at any given pressure, have capacities which do not lessen very much with decrease of size, the dielectric loss of small cables is therefore disproportionately large. For example, in the five sizes given, the section increases in the ratio 1 to 17, but the capacity only as 1 to 2·28.

The carrying power of a cable is limited in most cases by drop of volts rather than by heating or loss of power,

otherwise this dielectric loss would very much restrict the load that could be put on cables.

Nevertheless, this loss seriously affects the question of raising the pressure for long distances or large powers, at least where underground or covered conductors have to be used. As the copper loss is inversely as the square of the current, the temptation is to increase the pressure and reduce the current. But the dielectric loss being proportionate to the square of the pressure, and being moreover a constant or all-day loss, whereas the copper loss is only fully felt at times of full load, limits to increase of pressure are imposed which may be reached sooner than has been supposed.

This opens a field for very careful consideration—and balancing of advantages—of high and low (or lower) pressure. I do not attempt to make any comparisons now. Every case must be examined on its merits and due weight given to load-factor, drop, value of power, plant capacity, and so on.

I believe the general opinion has been that the production of capacity current involved practically no expenditure of energy; that it was in reality a wattless current, and that the only waste—a sufficiently considerable one—was in running the alternator under light load. I think nothing contrary to this opinion was put forward before the recent parliamentary committees on power bills. Those committees were assured, for instance, that so far as power was concerned, the losses with underground cables were the same as with aerial lines. I fear this is by no means the case. I do not wish to adopt an alarmist tone on this subject, but I think it will be admitted that if the tests referred to above are even only approximately correct, the subject deserves the very serious consideration of electrical engineers.

It is probable that those who have had to do with extra high-tension mains, or even with long or extensive mains working at moderate high pressures, will have noticed, as I have, that when switching such mains on, the engine has been checked much more than would be consistent with the production of merely wattless current.

We may now pass from the question of the power-factor and the true power, to the wattless part of our "apparent

watts." This we see is about 87·6 per cent. or 7-8ths of the total.

It is very desirable we should do anything we can to lessen the production of "wattless current" by the alternator, as the amperes are real even if the watts are not.

In producing "wattless current" at full pressure the alternator is taking a good deal of power, and is working very wastefully as to steam consumption. It takes practically as much plant to produce the current as if the energy were real. In fact it might easily happen from the known wastefulness of engines working at light load and from other causes that the true energy would cost less to produce it than the false or wattless energy. For example, to charge 20 miles of the 6,000-volt cable referred to above (and assuming that no means are used to counteract the capacity) the alternator would have to be run at 6,000 volts sending out $1·621 \times 20 = 32·4$ amperes $= 194,500$ apparent watts or 260 apparent E.H.P. This would require a 200 kw. alternator fully loaded so far as current is concerned, although the true energy would only be $194·5 \times ·124 = 24$ kw.

As there are objections to running a large alternator by a small engine, a large combined plant is often run on a low power-factor circuit.

Fortunately the difficulty can be avoided very simply, by the application of known principles. To some extent this is done now, but I think it is done accidentally or unconsciously, or at least without system.

In explaining how the wattless current may be reduced and the power-factor raised to unity or nearly so, I hope those who prefer the mathematical treatment of such questions will not be impatient at my attempts to express my meaning in the vulgar tongue.

In a conductor or circuit having capacity the charging current has a positive phase displacement of 90° from the E.M.F., while the current in an inductive circuit has a negative phase displacement of 90° from the E.M.F. Thus there is a difference of phase of 180° between these two currents. This is well known. Its systematic application affords a solution of the problem we are now considering.

Imagine an alternator supplying a circuit having capacity. Then if an inductance or choking coil is put in parallel with the capacity, and if it is so designed and adjusted that it takes

a wattless self-induction current equal in amount to the wattless capacity current of the mains the two will balance one another, and the generator will not have to produce any wattless current for either the capacity or the self-induction. Each will take its full current, which will pass to and fro between the capacity and the choking coil, being alternately a capacity or charging current with a positive phase displacement and a self-induction current with a negative phase displacement. The generator will only have to keep up the E.M.F. and to produce the energy component of the current for the cable and the energy component of the current for magnetising the choking coil, and for leakage

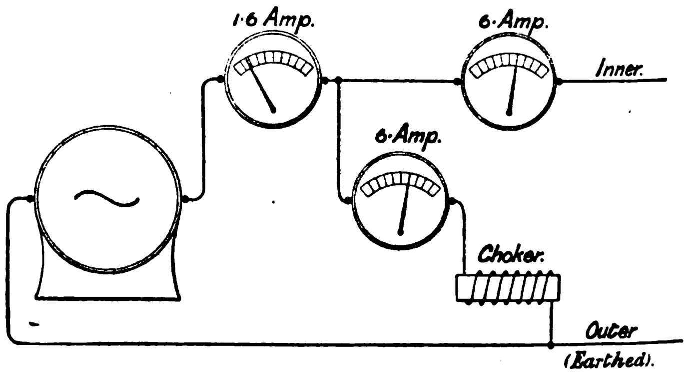


FIG. 4.

and resistance losses. As these energy currents are in phase with the E.M.F., the alternator will act as if working on a circuit having neither capacity nor self-induction—that is, a circuit having a power-factor of unity. This will at least be the case if the balance is perfect.

By the kindness of Mr. Sparks and the County Company, I have been able to try some experiments on the $5\frac{1}{2}$ miles of mains already alluded to. The arrangement is shown in Fig. 4.

I made a choking coil to take 6 amperes at 2,000 volts 100 $\sim$. Particulars of this coil are given later on. When working at 2,000 volts 100 $\sim$, the alternator gave 6 amperes when connected to the cable alone. The current was also 6 amperes when the alternator was working on the inductance coil alone. When the cable and the coil were

put in parallel, with ammeters in circuit as shown, the alternator produced 1·625 amperes only, although there was still a current of 6 amperes in the cable and 6 amperes in the choking coil.

There was not a perfect balance. The true watts taken by the cable and the choker were about 2,000, therefore the alternator current should have been only about 1 ampere, but I was not able to get a closer adjustment. I must have had very nearly the best balance obtainable, as any adjustment of the choking coil, either in the direction of increasing or of decreasing its current, caused an increase in the alternator current. Possibly the slightly imperfect balance was due to a difference of effect of a sine curve alternator on the choker and on the capacity.[1] The actual practical result, however, was quite satisfactory, as the choking coil effected a saving on the system of about 9,000 apparent watts, the energy absorbed by it being about 500 true watts. I need not say that the saving under these circumstances is not only "apparent."

It is not easy to say what would be a fair estimate of the cost of producing "wattless energy" I venture to think it is not much less than one-fourth of the cost of true energy.

Whatever figure is taken, the desirability of economising in such matters will be realised when I point out that at one penny per E.H.P. — hour one watt for one year costs one shilling,[2] or say £1 capital.

DESCRIPTION OF CHOKING COIL.

This description is not given as that of a very satisfactory example of design, but to show the coil used, and in the hope that it may be of some interest to designers of such apparatus. The main dimensions of the coil used in these tests are given in Fig. 5. It consists of a set of E stampings, with a coil wound about the middle projection. The "yoke" is straight and is carried on supports, allowing of adjustment of the gap. Fig. 6 gives the currents with various air-gaps.

The current taken by the coil at 2,000 volts 100 ∿ with various air-gaps is given by Fig. 3. The form was chosen in preference to the simple straight coil form, as a convenient one for adjustment, and because it gives an external field more suitable for enclosing in an iron core.

[1] See paper in Journal XXIX., p. 154, Jan., 1900, by Alexander Russell, according to whom a sine curve wave gives a smaller condenser current and a larger magnetising current than any of the other wave shapes considered in his paper.

[2] Or, more precisely, 11·74 pence.

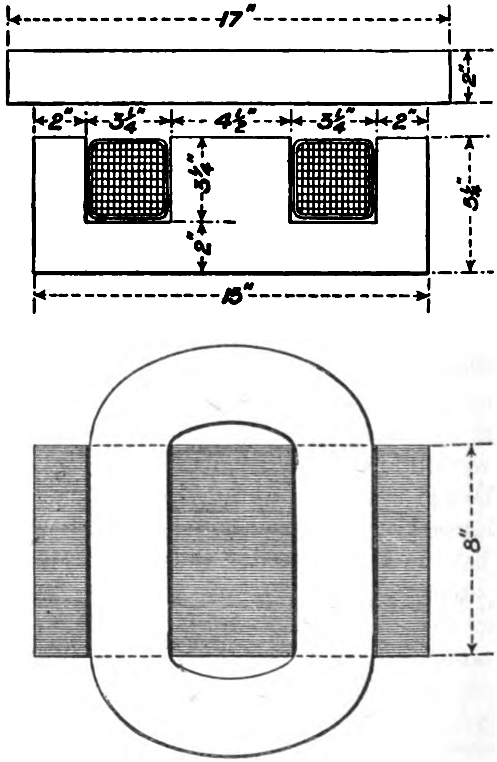


FIG. 5.—Choker for 12 Apparent K.W.

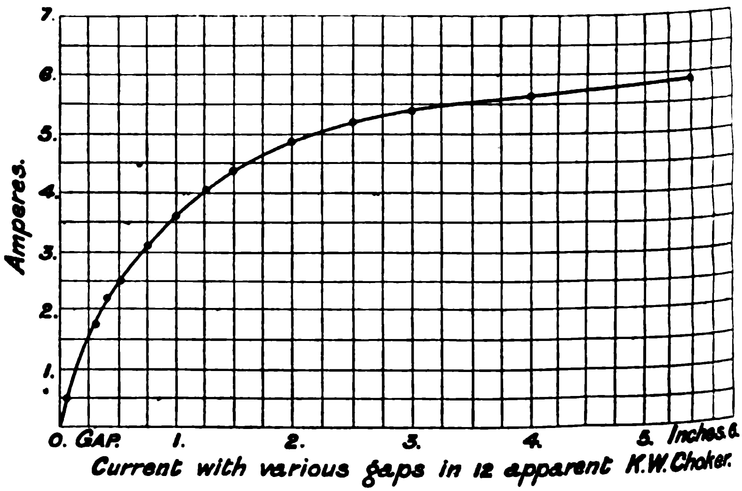


FIG. 6.

The cross-section of the core is about 29·76 sq. in., or 192 cm. of actual iron—weight about 190 lbs.

The winding consists of 756 turns of 0·08 in. wire, having a total length of about 2,600 ft. and a resistance of about 4·1 ohms.

At 2,050 volts 100 $\sim$, N = 6,081,000, B = 3,170.

The iron is 0·014 in. thick of a quality which would have a loss in a closed-circuit transformer of about 0·55 watts per pound. The iron loss should, therefore, be about $190 \times 0{\cdot}55 = 104{\cdot}5$ watts, with the yoke closed down. With the yoke removed (as used) it should have a loss of about 68 watts if the circuit completed itself through the air.

The copper loss with 6 amperes $= 6^2 \times 4{\cdot}1 = 148$ watts. Total, 216 watts.

The tests, however, show a loss of about 500 watts. The difference must be due to eddies caused by magnetic leakage. The stray power is higher than would be expected, but it answers its purpose very well. Its power-factor is $\frac{500}{12{,}500} = 0{\cdot}041$.

I know of no published information on the losses in choking coils, and suggest it as a useful subject for study. The principal difficulty is in testing apparatus having such low power-factors.

The weight is about 22 lbs. per apparent K.W.

I have said that in reducing the capacity current required to be produced by the generator, something was effected in ordinary practice, but accidentally, or at least not systematically, by the action of all self-induction in the system—for example, that of transformers or motors. In transformers the effective self-induction is very small. The no-load current is small in good closed-circuit transformers, and the power-factor is high—usually from about 0·7 to about 0·85. The wattless component available is therefore very small—at least, in modern systems having large and efficient transformers. No doubt if the conditions of a circuit are known from the first, the transformers may be so designed as to provide the capacity current, at least at light load ; but it would be difficult to do this systematically as the conditions in practice are so variable. With a large number of small transformers it may be that the wattless capacity current may be compensated or more than compensated.

I do not think transformers of low power-factor should be used. I believe the better plan will be to continue to make transformers with small no-load current and high power-factor, and provide separately for any compensation that may be necessary.

When motors are used, their large, idle, lagging current is available to compensate the capacity. Where there is a large motor load the idle current will usually be a lagging rather than a leading current, even on mains of considerable capacity. A synchronous motor, as is well known, acts either as a capacity or a self-induction according to the excitation. When over-excited, it acts as a capacity and takes a leading current from the mains; when under-excited, it acts as a self-induction, taking a lagging current. When excited to take a minimum current it has no idle component —that is to say, its power-factor is unity. Such motors running light are now often used for balancing self-induction, but I have never seen them used for balancing capacity. In any case they are a rather expensive remedy, as they have to be practically as large as if they were to do real instead of only apparent work. Their first cost, their working costs, and losses are therefore high. For balancing self-induction they may be necessary. I hope, however, that for this purpose condensers will again be taken up by Mr. Swinburne, or somebody else. Probably their hysteresis loss will not be as great as the losses in motor compensators nor their working cost or first cost as high.

But in any case, the running of under-excited synchronous motors is an expensive and clumsy way of compensating capacity, compared with simple choking coils, such as I suggest.

Such coils, used with a phase-indicator, should be useful in all systems where the capacity current is large enough to deserve attention.[1]

There is something very disproportionate and anomalous about the two classes of loss in the dielectric—the insignificant losses due to leakage, and the large apparent and actual losses due to capacity and hysteresis.

Let me take for illustration a 10,000-volt cable having one-third microfarad capacity per mile, and working at

[1] I may mention that when I applied for a patent for this method my attention was drawn by that useful institution, the German Patent Office, to the fact that, so far as concerned the treatment of a long transmission line by choking coils placed at intervals, I was anticipated by Charles Schenck Bradley, the well-known American electrical engineer (British Patent 20,493 of 1897). Reference should also be made to the proposals of our president of last year, Prof. S. P. Thompson, to compensate the capacity of submarine and other cables to facilitate signalling by placing high-resistance choking coils at frequent intervals along their length. See his British patents 22,304 of 1891; 13,064 and 15,217 of 1893; and 13,581 of 1894.

50 $\sim$. Its insulation is, say, 2,500 megohms (it may be only a few megohms without affecting the argument). The dielectric has several functions. It acts as a nearly perfect non-conductor. But it does conduct a little: it allows $\frac{1}{250,000}$ ampere to pass through it, = 0·04 watt per mile.

Then there is the electrostatic action. From Table I. we see the capacity current is 1·05 ampere, the apparent watts 10,500, and the real **watts** 1,296, or 32,400 times the watts lost by conduction.

This is an interesting state of things. Both dielectric conduction and dielectric hysteresis waste energy in the same way—by heating the dielectric. We use an insulator which reduces the leakage energy loss to ·04 watt per mile, but allows another energy loss 32,400 times as great.

So far as loss of energy is concerned we should be just as well off—or as badly—with an insulation resistance of $\frac{10,000}{1 \cdot 05} = 9,524$ ohms, instead of 2,500,000,000. The energy spent on our dielectric would be just the same, and I suppose we should have no wattless current at all! I point this out to illustrate an anomaly, not to make a practical suggestion. It may be that no low resistance insulator can be found capable of resisting breakdown under such conditions.

I have spoken of the energy component of the capacity current spent on heating as if it were in some way different from the leakage current. It only differs from it in amount. It is not recovered like the true charging current. It does not surge to and fro in the cable. In all practical essentials it is a leakage current. It goes right through the dielectric, and heats it in its passage exactly like the leakage current. The effect of capacity in allowing the passage of this current is precisely as if it reduced the insulation resistance in the proportion I have suggested, viz., from 2,500 megohms to 9,524 ohms.

At least this is how it appears to me.

With aerial lines capacity effects are comparatively unimportant. For example, with wires of $\frac{1}{3}$-inch diameter, hung two feet apart, the capacity per mile is only 0·018 microfarad. Not only is the wattless current therefore small, but there is no "wattful" current.

AN ALTERNATE-CURRENT WATTMETER.

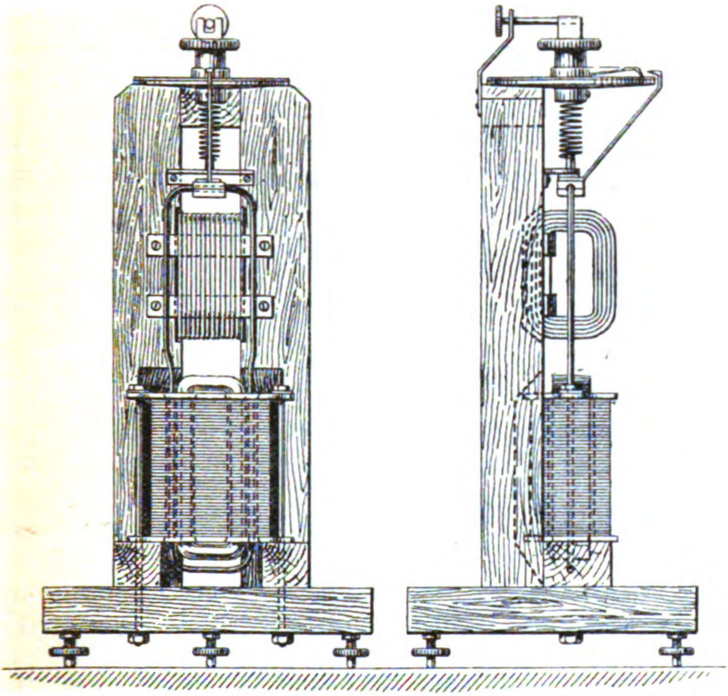
In concluding this paper I wish to describe an alternate-current wattmeter especially suitable for measurements such as are required in connection with the subjects treated in this paper. In devising this instrument my aim was to get a simple, strong, reliable wattmeter—one that needed no resistance added in its E.M.F. circuit, and that would absorb very little energy in that circuit even for large E.M.F.'s. In such an instrument the E.M.F. coil should have a large force, and at the same time be practically without self-induction, and should be correct with all power-factors met with in practice. If possible it should be correct through a considerable range of periodicity.

Long and satisfactory experience of the Siemens dynamometer under workshop conditions made me turn to it as the most suitable type of instrument, and to try to devise means by which it should have the qualities just enumerated.

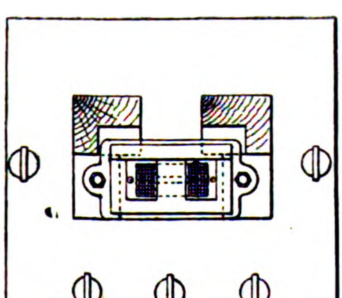
Fig. 7 shows the instrument in elevation and plan. Fig. 8 is from a photograph of an actual instrument.

The Siemens dynamometer form is closely followed. The series or current coil is placed in the ordinary position. Under this coil is a small transformer, the primary winding of which is wound for any required E.M.F. Next to this primary winding a space is left at each side—the space usually occupied in a transformer by the secondary winding. In this space a closed coil of one turn of wire is suspended freely—the wire is platinoid, manganin, or some other conductor having a negligible temperature co-efficient. This conductor is suspended and controlled exactly like the suspended coil of a Siemens dynamometer. It acts as the secondary of the transformer. As it is closed on itself no mercury cups are needed. Its circuit external to the transformer consists simply of a loop passing up the front and down the back of the fixed or current coil.

The action will now be understood. A comparatively large current of very low pressure is generated in the secondary coil. This current is in opposite phase to the E.M.F. It passes through the field of the fixed or current coil. The suspended conductor is acted on and deflected by the current in that coil, and is brought back to zero by the tension of the spring as in an ordinary dynamometer.



FRONT ELEVATION. SIDE ELEVATION.



PLAN AND SECTION THROUGH TRANSFORMER.

FIG. 7.

It will be seen that so long as the iron of the transformer is not forced to too high a density by using too great an E.M.F. or too low a periodicity, the secondary current will be proportional to the E.M.F. and independent of the periodicity. The magnetising component of the primary current and the energy spent in the iron will vary with the E.M.F. and periodicity, but if the self-induction of the secondary coil is sufficiently low this will not affect the proportionality of the secondary current to the primary E.M.F.

The instrument shown on the table is the first I have had made. It has been kindly constructed to my drawings by Messrs. Siemens. By tests made at the Board of Trade Electrical Laboratory (in connection with which I have to thank Mr. Trotter and Mr. Rennie), I find my anticipations have been verified—the instrument has the same constant with power-factors of 1 and of 0·1, and it is proportional all round the scale.

This kind of instrument may easily be made for a large range both of E.M.F. and current, as the primary of the transformer as well as the current coils may be variously wound or connected—the suspended secondary conductor being always the same.

In the instrument exhibited the current coils are three in number, of varying section—the transformer primary being suitable for any E.M.F. up to 500 volts at 100 ∿. The range is as follows:

Fine coil,	for maximum	of about	2·5	amp.,	constant	1·25	watts	per	division.
Medium	,,	,,	15	,,	,,	6·8	,,	,,	,,
Thick	,,	,,	90	,,	,,	37	,,	,,	,,

This is at 83 ∿. There are 400 divisions in the circle.

I have not succeeded, in this first attempt, in making the instrument independent of periodicity. The variation is about 10 per cent. between 30 ∿ and 90 ∿. In using the instrument it is therefore necessary to know the periodicity. I hope to greatly reduce this variation, or perhaps get rid of it altogether through a sufficient range for practical purposes. Even as it is, it will perhaps not be considered a very serious objection.

The principle of this instrument may be readily applied

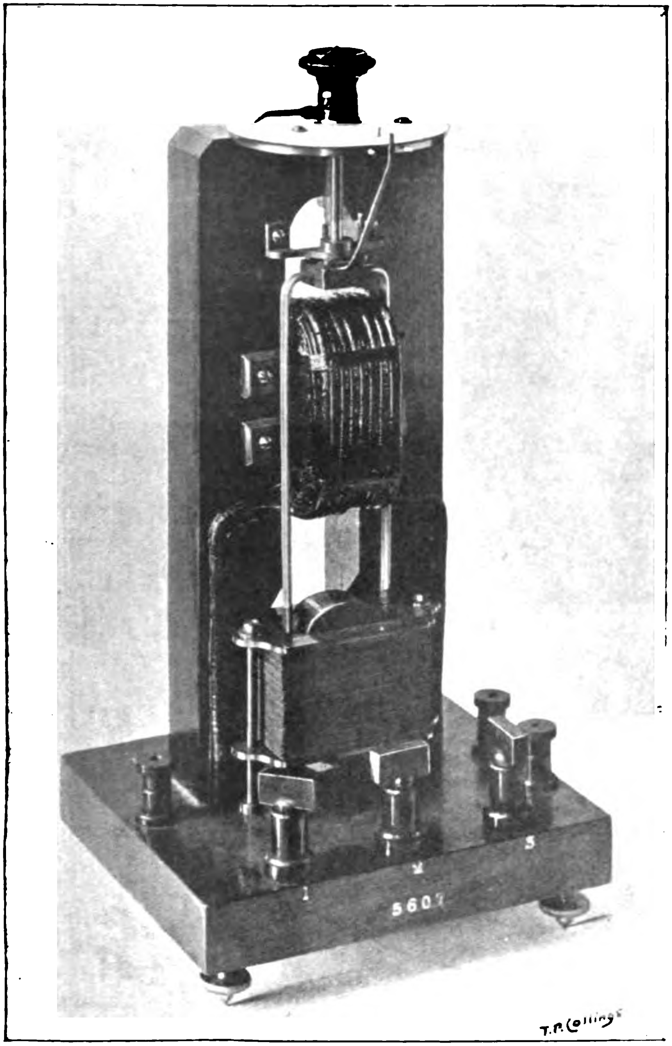


Fig. 8.

It will be seen that so long as the iron of the transformer is not forced to too high a density by using too great an E.M.F. or too low a periodicity, the secondary current will be proportional to the E.M.F. and independent of the periodicity. The magnetising component of the primary current and the energy spent in the iron will vary with the E.M.F. and periodicity, but if the self-induction of the secondary coil is sufficiently low this will not affect the proportionality of the secondary current to the primary E.M.F.

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Fine coil,	for maximum of about	2·5	amp., constant	1·25	watts per division.
Medium	„ „ „	15	„ „	6·8	„ „ „
Thick	„ „ „	90	„ „	37	„ „ „

This is at 83 ∿. There are 400 divisions in the circle.

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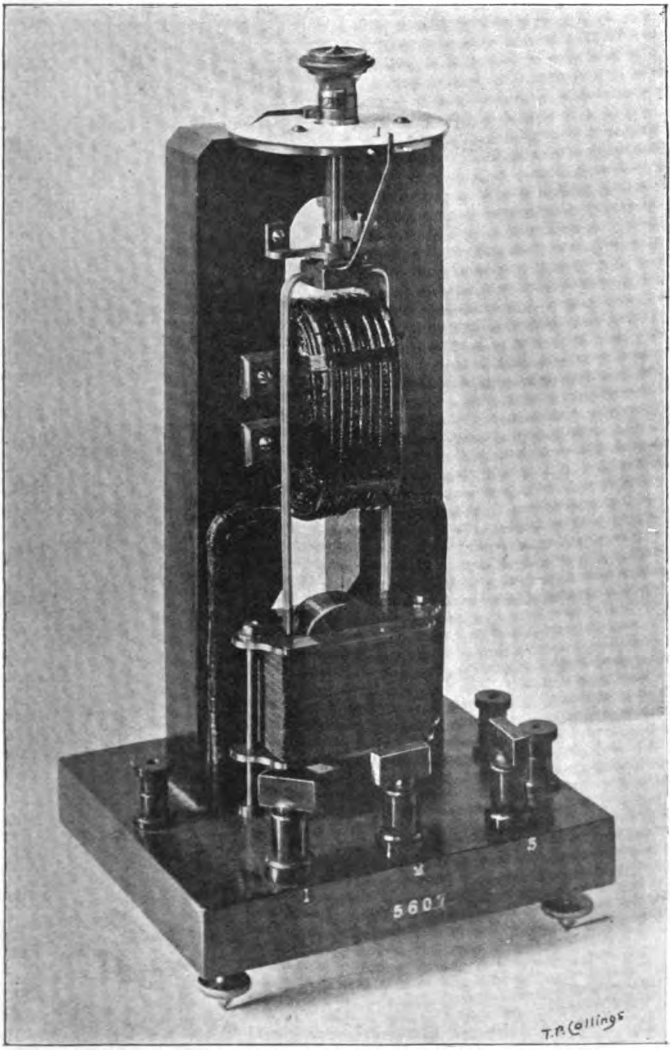

Fig. 8.

to other forms, but it would be premature to describe them here.[1]

In this paper I have not attempted to treat of several aspects of "Capacity in Alternate Current Working"—matters perhaps as important as those I have tried to make clear. I have avoided comparisons between different kinds of cables. I have considered single-phase only, not two- or three-phase. I have said nothing of effects of capacity on regulation, on distribution of potential along lines, on liability to rupture of insulation due to capacity, or on means for reducing such liability. In keeping to one aspect of the subject, I have hoped to be of most use to my fellow Electrical Engineers.

I have to express my thanks, for information or facilities afforded me, to Mr. Gray and the Silvertown Company, to Mr. Edmunds and Mr. Howard of Messrs. Glover & Co., to Mr. Nisbett and the British Insulated Wire Company, and to Mr. Gavey (Chief Engineer of the Post Office). Also to Mr. Dallas and Mr. Grafton, respectively of the Silvertown and the County Companies, for assistance in experiments. I have already mentioned my indebtedness to Mr. Sparks and the County of London and Brush Provincial Company.

Professor W. E. AYRTON: The first two or three pages of Mr. Mordey's paper, he tells us, are given in order to impress upon central station engineers that they have in their possession a very easy means of measuring the capacities of their cables, and I presume by that he implies that they do not use these means. If that be the case, then who is to blame? Is it because the method has not been put before them? or is it because, after the method has been put before them, they have neglected it? The matter of measuring the capacity of real cables in this way was brought prominently before me a good many years ago. It was brought to my notice in the very beginning of the Deptford Generating Station when, as you know, power began to be transmitted from Deptford to the Grosvenor Gallery, through six underground cables each some six miles in length. I was very often at that time in Deptford with Mr. Ferranti, and one day Mr. Ferranti put to me this question: he said, "Can you explain this to me, because to me" (that is, to Mr. Ferranti) "it is very curious. I find that during the daytime, when there is practically no load on in the Grosvenor Gallery, the ammeter reads a fairly large value, and when the load comes on in the evening, the ammeter reading does not go up very much. What does it mean?" Professor Ayrton.

[1] I should mention that some years ago Mr. Swinburne proposed or made an instrument in which he pivoted a closed-circuit conductor—this had a current induced in it, and was deflected by the flux in an air-gap in which it hung.

Professor Ayrton.

I had then, at that time—I am speaking of eleven or twelve years ago—to go into this question in detail with Dr. Sumpner, who was with me as an assistant. We sent to Mr. Ferranti a complete account of the cause, and explained that during the daytime he was practically measuring the capacity of his cable by means of the alternating current flowing into it at a known pressure and frequency. Having had our attention directed to this, we measured a considerable number of capacities in this way; and finally, on March 6, 1891, Dr. Sumpner and I brought the matter before the Physical Society, and gave not merely formulæ, but the exact results that had been obtained with this method. We were not dealing with small capacities merely, such as Mr. Mordey has dealt with—a microfarad or so—our capacities went up to 89 microfarads. We were dealing, in fact, with hundreds of miles of cables as regards the capacity.

The same method was subsequently described by Dr. Fleming, on May 7, 1891 (pp. 395 and 396, vol. xx. of our Journal) and by Major Cardew on May 21, 1891 (p. 448 of the same volume), and in each case the results of actual experiments were given.

Further, about this time, condensers were made for me and for others by Mr. Swinburne, graduated *not* in microfarads, but in the currents which they would take respectively at 2,000 volts at 100 ∿.

Mr. Mordey.

Mr. MORDEY: Might I explain my position? I do not claim to have invented capacity current, or to have invented the fact that a capacity current will cause an ampere-meter to deflect. I merely pointed out that in Professor Ayrton's book on "Practical Electricity," where several methods are given, this simple practical method, not only in his book, but in a great many others, is not given. It is an engineering method that probably would not occur to people who are writing books of that class.

Professor Ayrton.

Professor AYRTON: The remark of Mr. Mordey is irrelevant. Volume I. does not say one word about alternate currents; in fact, it states very distinctly in the preface that only direct currents are supposed to be dealt with in this volume. It would therefore have been an absurd thing, in a book which deals wholly and solely with direct currents, to talk about an alternate current method of measuring capacity.

The paper to which I have referred, that was given in 1891 before the Physical Society, was called "Interference with Alternate Currents," and the reason why it had that name is because it dealt not only with what I have been referring to, but with the next part of Mr. Mordey's paper; that is to say, the combination of self-induction with a capacity. It gave numerical results that were actually obtained in this way, and on page 572 of the *Electrician* for March 13, 1891, it is stated in the abstract of this paper:—

"On joining a condenser and inductive coil in parallel, an ammeter in the main circuit indicated 5·5 amperes, whilst those in the branches showed 6·4 amperes passing through the condenser and 10 amperes through the coil. Other experiments of a similar nature were described, and it was pointed out that the ratio of the sum of the two parts to the measured total may be large, being about eight in the case just

Professor Ayrton.

mentioned." It is interesting to notice that, as a matter of fact, this ratio was exactly the best result that Mr. Mordey could obtain with his combination described in his paper of to-night, *i.e.*, ten years later.

The abstract in the *Electrician* goes on to say: "Theoretically this ratio might be anything, depending as it does on the phases of the pressures in the two parts, and these phases are determined by the ratio of the impedance of the coil to its resistance; practically, however, it was not easy to get a coil of large self-induction and very small resistance."

This last remark is interesting in showing that Dr. Sumpner and I were occupied at that time *not* in applying a condenser to a self-induction, but in carrying out exactly the experiment described by Mr. Mordey in his paper of to-night, viz., that of applying a self-induction to a capacity for the purpose of reducing the capacity-current that would otherwise flow in the leads bringing the current to the condenser.

But now, if we take Mr. Mordey's own experiment, I say that by dealing with the principles given in that 1891 paper of ours, without going a step further—and that is the best proof of what was in that paper—I can enormously improve his result.

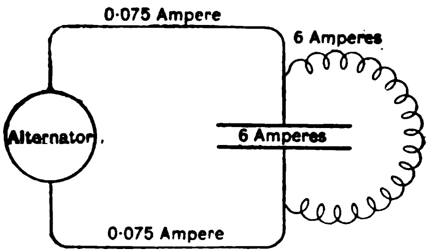

FIG. A.

For if F be the capacity of a condenser, or cable, in farads, p be 2π times the frequency of an alternator sending current into the cable, V be the R.M.S. value of the sine wave of P.D. produced by an alternator, and o the resistance, in ohms of an inductive resistance placed as a shunt to the condenser, then the current in the alternator circuit will be a minimum and equal to

$$\frac{VFo}{p},$$

when h, the self-induction of the inductive shunt, has a value

$$\frac{1 + \sqrt{1 + 4 F^2 p^2 o^2}}{2 F p^2} \text{ henry.}$$

Now, in Mr. Mordey's case this best value of h becomes 0·53 henry, and with a shunt to his cable, *made without any iron* and having this self-induction and a resistance of four ohms (the resistance of his choker), the alternator current will be found to reduce itself to as little as 0·075 ampere, if V be 2,000 volts, the frequency 100 $\sim$, and the current due to dielectric hysteresis is inappreciable.

Professor Ayrton.

Mr. Mordey ought to have used no iron at all in his choker, and what I propose to do is to supply Mr. Mordey with an inductive coil properly constructed for his case, and he will find that, with sine waves, the alternator-current will be much less than 1·6 amperes, and the power wasted in my coil much less than the 500 watts which was expended in his choker.

Mr. Mordey will say, But how is it possible with any coil of any shape whatever to reduce the current to anything like that when you have this dielectric hysteresis loss? That brings me to really the most important part of his paper, that is to say, the loss in the cable. I should very much like to ask Mr. Mordey whether he has sufficiently tested either the cable or what he calls the "Thomson recording wattmeter"—for him to feel at all sure that, with the low power-factor he is dealing with, the instrument indicated correctly. Mr. Mordey very rightly said that he did not use an ordinary wattmeter, because with such a low power-factor it was very difficult to get accurate results; but he seems to forget that the error in the Thomson watt-hour meter, as it ought to be called, or energy meter, is even much larger. If he will refer to a paper in the *Electrical Engineer* of March 24, 1893, he will see the question of the Elihu Thomson's watt-hour meter dealt with. The error in the watt-hour meter—and how it can be calculated—is discussed; and then experiments are given showing that the actual errors when the instrument is employed on an inductive circuit is as is given by the formula quoted. Now, if you will take that formula—which is the formula I worked out years ago, for a wattmeter—and apply it for such a low power-factor, you will find, unless I am very much mistaken, that the power indicated by an energy meter may be considerably larger than the true power.

I feel certain, therefore, that the explanation of Mr. Mordey's high power-factor is either that his energy meter—for the reasons stated in this paper in the *Electrical Engineer* of March, 1893—gave an answer which is much higher than the truth, or the cable that Mr. Mordey used was an exceptionably bad cable.

The matter is of enormous importance. We are not dealing with any question of priority, or whether central station engineers have or have not studied what has been written; but we have to consider this—What is the true loss in a cable? I mean the loss due to this so-called dielectric hysteresis. One reason why I am inclined to think that it is far less than Mr. Mordey imagines is that in all previous measurements which have been made by myself, by Major Cardew, and others, the power-factor has come out far smaller than the value Mr. Mordey gives now, the power-factor meaning the ratio of the true power wasted in dielectric hysteresis to the apparent power given to the cable. In the case of Mr. Swinburne's own condensers we found that it was something of the order 0·01. In the experiments made by Major Cardew, which appeared in the Institution's Journal in 1893, the values vary in different experiments from about 0 watts loss to 4·8 watts loss. If you take his highest value, his power-factor is 0·063; if you take his lowest value, it is nought; and taking the mean we see that he was dealing with a power-factor under 0·03.

If, again, you refer to experiments which have been made by Lombardi on this very subject of the hysteresis loss of various dielectrics, you will find that viscous substances like paraffin wax appear to have a power-factor of about 0·088, and gutta percha 0·042. Lombardi's results are very interesting, because for petroleum he got 0·014, and for condensers which have petroleum smeared on them or poured on them we found years ago, in 1894, I think, the power-factor was about 0·01. The result seems to be this: that, if the cable which Mr. Mordey tested has really a power-factor of 0·124—that is to say, if one-eighth of the whole of the power given to the cable is really wasted—then the cable is made most unnecessarily bad, because if you make the cable with any of the other materials referred to above, you ought to get a power-factor very much smaller. It is a matter obviously that can be very carefully tested, and it is a matter which I thoroughly agree with him ought to be tested if there is really any doubt about the matter, because it is of vital importance in connection with these power transmissions through long lengths of underground cables. In order to test it, I would ask Mr. Mordey if he would be good enough to allow me to find out the exact nature of the error—whether the instrument used was an ordinary wattmeter or an integrating wattmeter—which led it to give this extraordinarily high power-factor. Professor Ayrton.

The PRESIDENT: Mr. Mordey asks me to allow him to make some reply to Professor Ayrton's remarks, without waiting until the next meeting. The President.

Mr. W. MORDEY: I wish to say before the meeting closes that I have every reason to believe the power-factor was properly determined. The wattmeter was calibrated in the well-equipped laboratory of the Westinghouse Company, especially with a view to finding out its constant with low power-factors. I accepted the readings of the instrument. If I had not felt that the fact of a considerable loss of power in mains was confirmed indirectly and broadly by general observations in central stations, I should not have said anything about the power-factor at all. I have not any doubt whatever that there is a considerable loss of power in the insulating materials of cables. If this is the case, you will agree with me that it is sufficiently important to merit attention. I do not want you to go away and think that I have put forward a figure of that sort, a figure that is very important indeed in practical engineering works, without having a reasonable belief that it was based on accurate facts. However, the instrument can easily be calibrated or further tests taken, and I will, before the end of the discussion, see if I can give further information. Mr. Mordey.

On the motion of the PRESIDENT, a hearty vote of thanks was passed to Mr. Mordey for his paper.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Members:

Sir John Wolfe Barry, K.C.B., F.R.S.	Bertram Sands Giles.
	Sidney Howe Short.

Associate Members:

Alan Neville Banister.
John W. Black.
Watson Blagburn Carrick.
George Alexander Clark.
James Herbert Clothier.
John Wylie Donaldson.
Christopher Elliott.
Alexander Gerrard.
Arthur Hewitt Gilling.
A. J. Harris.
John McNab Hunter.
William Livingston King.
Edgar John Kipps.
William McAulay.
Peter Alexander McKillop.
William Nairn.
Walter Reilly.
Thomas Roles.
John Francis Stanley Scott.
John Severs.
Thomas William Sheffield.
Christopher J. Spencer.
James Ross Stevenson.
Charles Granville Vines.

Associates:

Harry Allcock.
Alan Arthur.
Joseph Bein.
George C. Blair.
Alec David Chalmers.
Ardesir Bomanjee Darookhana-walla.
Edwin Henry Dixon.
Paul Goldschmidt.
Edmund Goolding.
Thomas Stephen Hepworth.
William Hodgkinson.
James Lowson.
William Maclay.
William Mayer.
Edwin Morgan.
Henry James Moysey.
Gerald Mushet.
Felix Bernard O'Hanlon.
Franke Herbert Parker.
Frederick George Thomas Parsons.
William Richards.
Frederick William Richardson.
Alfred James Ryan.
Valentine Aloysius Ryan.
Edward Ashmore Thompson.
George Hamilton Thomson.
Fiennes Olive Trotman.
Charles Alfred West.

Students:

John Cruickshank Anderson.
John Alexander Armstrong.
Raymond Dorrington Bangay.
Arthur Wynne Barnley.
Frank Norton Bell.
Charies Henry Day.
Hugh William Geare.
Alexander Walter Harrold.
Horace William Holt.
John William Law.
William Marden.
William Robinson Myers.
Lionel George Nunes.
Frank Oldrieve.
Hubert Beaumont Shepheard.
Alfred Symth.
Vincent Dare Sorby.
Henry D. Stepanian.
Claude Stert.
Joseph P. Tierney.
Werner Anton Trier.
Frederick Wardrobe.
Hildred Edward Webb Bowen.
Richard Hubbard Welch.
Cecil Tom Wilkinson.
John Michael Faraday Wilson.
Horatio Peter Stanley Wise.
Joseph Julius Wolff.

The Three Hundred and Fifty-seventh Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, 25, Great George Street, Westminster, on Thursday evening, February 14th, 1901, —Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on January 10th, 1901, were read and approved.

The PRESIDENT: I took it upon myself to postpone the last Ordinary General Meeting which had been announced for January 24th. It was, I think, on Tuesday night that I felt that Queen Victoria being then very seriously ill it would be right to postpone the meeting. There was no time to call a Council meeting nor to send out postcards, but notices were sent to the daily papers and to those electrical journals that were likely to be published in time. At a Special Meeting of the Council of the Institution of Electrical Engineers held on the 7th February, the following resolution was carried unanimously:—

"That the Council of the Institution of Electrical Engineers, in Special Meeting assembled, hereby records its deep sense of the irreparable loss which the British Empire has sustained through the lamentable death of Her Majesty Queen Victoria, and its sorrow, in which each member shares, that one, who spent Her life for the good of Her people, and to whom Her subjects were affectionately devoted, has been removed from the scene of Her unremitting labours, and that a reign marked by unparalleled social, scientific, and industrial progress has thus been brought to a close.

"The Council humbly begs permission to express to His Majesty King Edward, and to the members of the Royal Family, its most sincere condolence and sympathy, and further to lay before His Majesty the assurance of its unswerving loyalty and devotion, and its earnest wishes that He may, with Her Majesty Queen Alexandra, long be spared to reign in happiness and peace over a loving and united people.

"It therefore directs that a sealed copy of this Resolution, with copies of Resolutions of Condolence passed by Local Sections of the Institution, be forwarded to the Home Secretary for transmission to His Majesty."

I may say that copies of resolutions have been received

Associate Members:

Alan Neville Banister.
John W. Black.
Watson Blagburn Carrick.
George Alexander Clark.
James Herbert Clothier.
John Wylie Donaldson.
Christopher Elliott.
Alexander Gerrard.
Arthur Hewitt Gilling.
A. J. Harris.
John McNab Hunter.
William Livingston King.
Edgar John Kipps.
William McAulay.
Peter Alexander McKillop.
William Nairn.
Walter Reilly.
Thomas Roles.
John Francis Stanley Scott.
John Severs.
Thomas William Sheffield.
Christopher J. Spencer.
James Ross Stevenson.
Charles Granville Vines.

Associates:

Harry Allcock.
Alan Arthur.
Joseph Bein.
George C. Blair.
Alec David Chalmers.
Ardesir Bomanjee Darookhanawalla.
Edwin Henry Dixon.
Paul Goldschmidt.
Edmund Goolding.
Thomas Stephen Hepworth.
William Hodgkinson.
James Lowson.
William Maclay.
William Mayer.
Edwin Morgan.
Henry James Moysey.
Gerald Mushet.
Felix Bernard O'Hanlon.
Franke Herbert Parker.
Frederick George Thomas Parsons.
William Richards.
Frederick William Richardson.
Alfred James Ryan.
Valentine Aloysius Ryan.
Edward Ashmore Thompson.
George Hamilton Thomson.
Fiennes Olive Trotman.
Charles Alfred West.

Students:

John Cruickshank Anderson.
John Alexander Armstrong.
Raymond Dorrington Bangay.
Arthur Wynne Barnley.
Frank Norton Bell.
Charies Henry Day.
Hugh William Geare.
Alexander Walter Harrold.
Horace William Holt.
John William Law.
William Marden.
William Robinson Myers.
Lionel George Nunes.
Frank Oldrieve.
Hubert Beaumont Shepheard.
Alfred Symth.
Vincent Dare Sorby.
Henry D. Stepanian.
Claude Stert.
Joseph P. Tierney.
Werner Anton Trier.
Frederick Wardrobe.
Hildred Edward Webb Bowen.
Richard Hubbard Welch.
Cecil Tom Wilkinson.
John Michael Faraday Wilson.
Horatio Peter Stanley Wise.
Joseph Julius Wolff.

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"The Council humbly begs permission to express to His Majesty King Edward, and to the members of the Royal Family, its most sincere condolence and sympathy, and further to lay before His Majesty the assurance of its unswerving loyalty and devotion, and its earnest wishes that He may, with Her Majesty Queen Alexandra, long be spared to reign in happiness and peace over a loving and united people.

"It therefore directs that a sealed copy of this Resolution, with copies of Resolutions of Condolence passed by Local Sections of the Institution, be forwarded to the Home Secretary for transmission to His Majesty."

I may say that copies of resolutions have been received

from the Local Sections of the Institution in Dublin, Glasgow, and Manchester, and telegrams have been received from our Local Sections at Calcutta and Cape Town. The resolutions are as follows :—

CALCUTTA LOCAL SECTION (*By Telegram*).

"The Members of the Calcutta Local Section send respectful condolences to His Majesty the King on the occasion of the national bereavement, and beg to assure His Majesty of their heartfelt loyalty."

CAPE TOWN LOCAL SECTION (*By Telegram*).

"The Cape Electrical Engineers desire to join with the Institution in expressing their heartfelt sympathy with His Majesty the King, and with the Royal Family in their great bereavement."

DUBLIN LOCAL SECTION. Resolution passed at Meeting on January 24th, 1901.

"That we, the Dublin Local Section of the Institution of Electrical Engineers, desire to record the deep grief with which we have received the news of the death of our late beloved Sovereign Queen Victoria.

"That this meeting do forthwith adjourn as a mark of our sorrow; and

"That if the Institution of Electrical Engineers propose to present a vote of condolence with the Royal Family, it is the desire of this Section heartily to endorse the same."

GLASGOW LOCAL SECTION.

(1) "That this Special Meeting of the Committee on behalf of the Glasgow Local Section of the Institution of Electrical Engineers, desires to express its deep sense of the loss sustained by the death of their late beloved Sovereign Queen Victoria, whose long and beneficent reign has been marked by such social and scientific progress."

(2) "That an expression of confidence and loyalty be sent to His Most Gracious Majesty King Edward, with the hope that He may long be spared to reign over His attached people."

MANCHESTER LOCAL SECTION.

"That we, the Manchester Section of the Institution of Electrical Engineers, desire to record the deep grief with which we have received the news of the death of our late beloved Sovereign Queen Victoria."

I have now to move that the Council Resolution be adopted by the Institution.

The resolution was then carried unanimously, the members rising in their places in silence.

The names of new candidates for election into the Institution were announced, and it was ordered that they should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

John Reid Dick.	James T. Rossiter.

From the class of Associates to that of Members—

Frank Broadbent.	Henry Herbert Reynolds.
Alfred Cecil Eborall.	

From the class of Associates to that of Associate Members—

Trevor Duesbury.	Sydney Cummins Smith.
William Jones.	William Paul Steinthal.
C. McCarthy-Jones.	Edwin A. Uttley.
Percy Sewell Sheardown.	

From the class of Students to that of Associates—

Arthur Daniel Crowther.	Kenneth Charles H. Newman.
Charles Jones Lockyer.	Arthur Woolmore Wigram.
C. Macmillan.	Herbert T. Wilkinson.
Christopher Oscar Milton.	Harold Henderson Williams.
Charles N. Nettley.	Walter Trevelyan Wright.

Messrs. J. M. Elliott and E. J. Howard were appointed scrutineers of the ballot for the election of new members.

Donations to the Library and Building and Benevolent Funds were announced as having been received since the last meeting :—To the *Library* from Messrs. Blackie and Sons, Messrs. Carré and Naud, the Radcliffe Library, Sir C. Todd (Member), and Mr. A. J. S. Adams (Associate). To the *Building Fund* from Messrs. R. J. Fuller, H. R. Carson, H. Lewenz, S. C. Smith, H. M. Kollé, J. H. Rosenthal, C. F. Farlow, S. L. Brunton, F. Langley, H. G. Andrews, J. L. Vogel, Lionel Wood, H. Kilgour, J. R. Penning, Mark Robinson, Kenelm Edgecumbe, Henry Lea, Colonel E. D. Malcolm, Lord Kelvin, A. G. Hansard, H. G. Thomson, A. Stroh, J. Maclean, Norman Endacott, Robert Hammond, H. J. Garnett, J. R. Bedford, R. O. Ritchie, H. C. Chamen, M. M. Gillespie, A. P. McDouall, A. D. Constable, F. H. Goodall, W. McGeoch, H. G. Beeton ;

and to the *Benevolent Fund* from Messrs. R. Vicars Boyle, M. S. Chambers, Kenelm Edgecumbe, Mark Robinson, Alex. P. Trotter, E. B. Thornhill, and H. J. Wagg, to whom the thanks of the meeting were duly accorded.

The PRESIDENT: We now pass to the adjourned discussion on Mr. Mordey's paper; but I will first ask Mr. Mordey to say a few words, as he wishes to do so before the discussion is resumed.

Mr. Mordey.

Mr. W. M. MORDEY: At the end of the discussion on the last occasion matters were left in a state of uncertainty. My paper was criticised by my friend Professor Ayrton with his usual energy—I will not say his wattless energy. His criticism now amounts to this—that what is new is wrong, and what is old is his. However, I am very glad indeed to have his criticism, and I hope that this matter, now that it is before the Institution, will be thrashed out thoroughly, so that we may feel at the end of it that, at any rate, we know a little more about it than when we began. Professor Ayrton has had this advantage—that the paper was sent to him by the President two or three weeks before any one else, so that he has had time for careful consideration before speaking. He has evidently come to the conclusion that his first reading of the paper led him to undervalue it, for after that first reading he took the trouble to call on me to point out that there was nothing in the paper at all except what he had been teaching his pupils for many years, and that there was nothing to discuss.

Before the discussion is renewed, I wish to be allowed to make a few remarks on two points. I wish to make a correction or an addition to a part of my paper. In the first part of my paper I drew attention to what I described as a well-known fact, that from the volts and periods and current you can calculate the capacity. I advised central-station engineers to use an ammeter to take the charging current, and to determine the capacity in that way. Professor Ayrton thought I had omitted to give him credit for having known that fact a great many years ago. I understand that he claims that as his method, invented by him years ago, and taught to his pupils ever since. As a matter of fact, it is a method that was common property before the dates he mentions, and he has no right whatever to claim it. I am, however, prepared to believe that he has been teaching it ever since. But, since he claimed it at the last meeting in that way, I was led to look into it a little, as I thought possibly it might not be right, and I found that as a practical method it was useless—that for the ordinary commercial conditions of electrical distribution by alternating current, the advice I gave to central-station engineers was not wise. I found that the current on a given capacity might be two or three times what that method would give. The explanation of this very serious possible error (as everybody will see when it is pointed out) is that the method demands sine curve E.M.F. waves. Such waves are not often met with in

practice, and apparently even slight departures from the sine form cause considerable difference in the current. There was not one word of warning given us by Professor Ayrton last week as to the enormous correction that might have to be applied in the use of this formula that he informed us he had been using for so many years. I know the correction is involved in the mathematical expression, but it is not sufficient to use a formula to entitle you to claim that you know all that is involved in that formula. This introduces a new definition of power-factor. If the current varies two or three times for a given voltage, the power-factor may vary in the same proportion, although the energy may be the same. It is very important that I should point that out. I ask those who may do me the honour of taking part in this discussion, if they refer to any results they have obtained, to state whether the power-factor they obtained is based on the ratio of the true watts to the volt-amperes, or is based on the calculated apparent watts with a sine function machine. Mr. Mordey.

There are other points that I should like to refer to, particularly as I gave a pledge at the end of the last meeting that I would try to give some further information on the point as it was left then, but as you, sir, evidently prefer that I should not do it now, I can only ask to be allowed to do it at a later time. I think perhaps it might put the matter on a little more satisfactory basis if I referred to it now.

Mr. C. P. SPARKS: Mr. Mordey in a commencing paragraph of his paper refers to the capacity of cables as a serious drawback to alternating current working. It is true that it is a disadvantage at times of very light load, but this can be largely neutralised by energising a minimum number of cables. Mr. Sparks.

In most E.H.P. stations there are two or more feeders leading to every distributing station, one of which can be used at times of light load, and extra mains can be connected with the rising load, thus reducing any inconvenience due to the leading capacity current to one-half or one-third, as the case may be. As most of the apparatus connected to the system, with the exception of the incandescent lamps, is of an inductive character, the capacity of the cables becomes a positive advantage and improves the load factor. The capacity and dielectric hysteresis of the cable vary with the character of the dielectric and the form of wave curve given by the alternator. The instance given by Mr. Mordey is for a rubber dielectric in which the capacity and power-factor are abnormally high. Had a paper dielectric been used in place of rubber, any inconvenience from capacity would have decreased to one-third for every mile of cable in circuit. Since the date when these cables were set to work, "paper" has almost entirely replaced rubber as a dielectric for such purposes. This is not only due to its lower capacity, but also to its very much lower price and greater durability.

In a later paragraph of his paper, Mr. Mordey alludes to the low efficiency of a large alternator running to supply the capacity current; or rather the large steam consumption of such a set on light load. Up to now, with the limited number of E.H.P. stations in England, the length of cables has in no case been such as to make the capacity current

Mr. Sparks. beyond the capacity of a small unit, and, although greater economy might have been reached by using still smaller units at times of light load, it is necessary, in case of a sudden demand, to have some reserve of power on the working plant. Under these circumstances, little advantage would be felt in any existing station if the capacity current was balanced by means of chokers at times of light load so as to cut down the size of the unit.

I should like to give some explanation of the figures on which Mr. Mordey has based part of his paper, namely, those relating to the loss of energy in dielectric hysteresis in this concentric rubber cable. Some eleven months since Mr. Mordey wrote asking me to give him permission to test, on one of our cables, his method of balancing the capacity-current with choking coils, and offered to construct a choking coil to demonstrate the reduction. Since this date, as pointed out in his paper, he has found the method was patented by Mr. C. S. Bradley in 1897. The first tests made in March reduced the current from 6 to 1·6 amperes, the connections being as shown on page 378 of Mr. Mordey's paper.

Following these tests, Mr. Mordey wrote asking me to consider the application of this method to our system of supply, and offered to construct a further choking coil which would still further reduce the idle current. Before coming to any decision in the matter, we made the further tests which Mr. Mordey has given in his paper, and I may point out here that these tests were made for our own purpose and not specially in view of their being used for any publication.

The figures were as follows:—

Cable. Concentric Rubber $5\frac{1}{2}$ miles; capacity, inner to outer ·86 m.f.; outer earthed; cable disconnected from switch board; insulation 6,000 meg. per mile.

Periodicity	100
Pressure	2,000 volts.
Watts in cable alone	1,509
Watts in choker alone	530
Watts in choker alone with keeper on	495

I may here point out that the meter revolved in one direction when connected to the cable and in the reverse direction when connected to the choker. The watts were then taken with both choker and cable in circuit, the choker having the keeper removed. The energy shown was 2,015, or within twenty-four watts of the tests made separately with leading and lagging currents. Assuming a low power-factor in the first tests, we must have had a much higher factor in the later, as the apparent watts were reduced to 3,200 as against 12,000. These figures were forwarded to Mr. Mordey, and he accepted the figure of 530 watts taken in his choker, although he points out in his paper that the calculated loss was 216, and accounts for the difference by eddies.

With regard to the use of Schallenberg Energy Meters for the purpose of measuring energy, a similar instrument to the one used with its transformer has been subjected to the following tests, the standard

Mr. Sparks.

of comparison being a Kelvin Electrometer Wattmeter specially arranged for alternating current-power testing under the supervision of the late Dr. John Hopkinson. In testing instruments against this standard it is found that a particular instrument can be adjusted to read true watts at a periodicity of 100 working on a non-inductive circuit, the pressure being supplied by an alternator giving a sine curve. The same instrument records energy within one per cent. when connected on a non-inductive circuit of fifty periods; thus, under these conditions, there is no periodicity error. On connecting the pressure coil of the instrument to an independent circuit, displaced 90 per cent. $\cos\phi$ thus equalling nothing, the instrument no longer revolves although the full-load current is passing through the series coil. The same instrument calibrated with $\cos\phi = \cdot 1$ $\cdot 2$ and $\cdot 3$ records the true watts within 3 per cent., at these phase differences the instrument giving identical readings whether supplied with a leading or a lagging current, (the direction of rotation reversing each time). These instruments have been used to check transformer core losses, and have been found to agree with the figures observed by other methods of measurement (power-factor here ·7 to ·8).

I was not able to be present at the last meeting of the Society, when Mr. Mordey's paper was read, but understand that Professor Ayrton severely criticised the figures given by Mr. Mordey. I, therefore, took an opportunity of reading Professor Ayrton's remarks, from shorthand writer's notes, from which I understand that he took exception to the loss of energy given, and predicted that, if tests were carefully made, the loss of energy would be found to be about one-tenth of the figure given. Under these circumstances, I thought it advisable to supplement the figures previously obtained by some other system of measurement, having in view that a possible error might have arisen in the energy meter used through the fact of it having been standardised on a machine giving a sine curve, and also in view of the fact that the same instrument had not been calibrated at two different periodicities at a low power-factor, although separate determinations were correct.

The method chosen was measuring the difference of power required to drive a generator driven by a direct-current motor. This set consisted as follows:—

(*a*) A two-phase 50-period machine having a capacity of 50 k.w. per phase.

(*b*) A single phase 100-period machine having a capacity of 100 k.w.

(*c*) The direct-current machine generally used for exciting the two alternators, and alternatively for starting them. The machine was constructed for carrying a large over-load for a short period for this purpose. The capacity of the direct-current machine was 60 volts by 125 amperes by 7·5 k.w.

On commencing this system of measurement, the first difficulty met was finding the current largely in excess of that given by the well-known formulæ—

$$C = \frac{V \times \sim \times K \times 2\pi}{10^6}$$

Mr. Sparks. the capacity-current being 2·1 times the amount given by this formulæ, the capacity having apparently increased by this amount. In order to check whether the difference was due to some wrong connection, an alternator, giving an approximately sine curve, was connected by the change of one connection only, when it was found that the capacity-current taken by the cable at once fell to the value expected from the formulæ. On repeating the test on the alternator previously used, the current at once rose to the value as given above. The motor generator readings of power when using the machine giving this abnormal result were as follows :—

Input into continuous-current motor, running the alternators at normal speed at 100 periods, the alternator being excited to give 2,000 volts from an independent source, 8 k.w. Ten miles of cable having I.R. dielectric of ·86 m.f. per mile inner to outer was then connected, when the power required to drive the motor rose to 14·4 k.w. Subtracting from this the light load and C^2R losses in the motor and alternator gives a balance of 3,160 watts losses in the cable. This giving a power-factor, taking the actual apparent watts observed on the cable, of ·069, the watts lost per mile being 316. Two tests at 100 periods were taken on separate occasions, the above results being the mean. From this it appears that, with the abnormal wave form of this machine at 2,000 volts pressure, a power of 316 watts is lost per mile at 100 periods, while the apparent capacity (and capacity-current) here is 2·1 times its normal value.

Another test was then made on one phase of the other alternator at 50 periods on the same cable, the alternator being excited to give 2,000 volts from an independent source. The results, taken in the same way as the other tests, give, as a minimum reading, a power-factor of ·04 on the observed current. The wave form of this machine must approximate to a sine curve, the difference in the capacity-current being only 9 per cent. from the calculated amount; the watts in the mean result in this case were 63 per mile, at 50 periods 2,000 volts.

Since making these measurements I have received a letter from Professor Ayrton offering Dr. Mather's services to make an independent test on the particular length of cable referred to by Mr. Mordey. These experiments were made this morning, and I have just received a copy of the results obtained from Professor Ayrton. The tests were made by energising a 5½ mile length of I.R. cable having a capacity of ·86 m.f. per mile from our substation, at a pressure of 2,250 volts from a transformer. The current flowing into the main was 6·8, showing that the transformer was giving approximately a sine wave. The current into the choker, which I understand had a weight of 80 lbs. copper and no iron, was 6·6. The actual current required to supply the main and choker combined was 2·7; this compares with the 1·6 obtained by Mr. Mordey. The energy was measured by means of a Ganz Wattmeter, of similar construction to a Siemens Dynamometer, having the moving coil wound with fine wire, and connected through a large non-inductive resistance with the pressure side of the system. The ammeters were hot-wire instruments, the pressure being measured on an electrostatic voltmeter, the periodicity being checked with a

periodicity recorder, and the wave form examined through Mr. Duddell's Oscillograph. The energy measured by wattmeter in both cable and choker was 798 watts; deducting from this the C^2R losses in the choker, we get 503 watts. Mr Sparks.

A test was then made with the choker in series with the cable, when the energy was found to be 763 watts; deducting C^2R losses in the choker of 281, the energy taken by the cable was 482 watts.

The current flowing into the cable is approximately that given by the formulæ for a sine curve, and this was further checked by the curve being examined on the oscillograph. The power-factor in each of these cases was ·034, and the power lost per mile of cable at 100 periods 2,225 volts being 96 watts.

These cables have been constructed for an ultimate working pressure of 6,000 to 6,600 volts at 50 periods, and on the assumption that the power-factor remains the same when the pressure is raised from 2,000 volts to this amount, the loss of energy will increase, taking the lowest power-factor found, namely, ·034, from 96 watts, as it is at present, to 335 per mile.

Taking 0·034, the power-factor found for this I.R. dielectric, and applying it to a practical instance we find:—That if four such cables, working at 6,000 volts and 50 periods, connect a distributing centre with the generating station, distant 12·5 miles, or a total length of 50 miles of cable; the annual losses from dielectric hysteresis are as follows (if all four mains remain under pressure the whole year):—

Maximum energy delivered per cable	600 K.W.
Taking three working cables and one spare, maximum energy delivered to the distribution station	1,800 K.W.
10 per cent. load factor	= 180 K.W.
Units delivered per annum $180 \times 8{,}760$	= 1,752,000
Losses in cable at 335 watts per mile.	

(On basis of power-factor of ·034, as found by Mr. Mather on I.R. dielectric when testing with a wave form approximately sine curve.)

$$\text{Losses} \qquad = 335 \times 50 \times 8{,}760 = 155{,}500$$

$$\text{Per cent. loss as above to units delivered} = \frac{155{,}000}{1{,}752{,}000} = 8{\cdot}3 \text{ per cent.}$$

If we substitute for this dielectric an (oiled) paper dielectric the capacity is reduced to one-third, and the power-factor to about ·025.

$$\text{The energy lost per mile (D.H.)} \qquad = 82{\cdot}0 \text{ watts.}$$

$$\text{Per cent. loss reduced to} = \frac{82 \times 50 \times 8{,}760}{1{,}752{,}000} = \frac{35{,}000}{1{,}752{,}000} = 2{\cdot}1 \text{ per cent.}$$

Under these circumstances I consider that, although Mr. Mordey has been premature in bringing forward this matter for discussion before obtaining comparative results from other cables having a different dielectric, the thanks of the Society are due to him for having pointed out the importance of capacity and dielectric hysteresis in alternating-current working, which has not had the

Mr. Sparks. attention of the bulk of our members although known to some. I am aware that by using other dielectrics a lower power-factor may be obtained; but, from tests on other dielectrics, it is clear that in the best cables the power-factor is about 2½ times the amount suggested at the last meeting by Professor Ayrton, while it is possible, as is shown by the figures I have given, to find, in exceptional cases, a power-factor which is 3½ times the amount.

In conclusion I should add that my best thanks are due to two of my assistants, Mr. Dallas and Mr. Smout, for their ready help in making the foregoing tests, and also to Mr. Gillespie, of the Westinghouse Company, for the great trouble taken in making special calibrations of the instruments used.

DIELECTRIC HYSTERESIS.

Concentric rubber cable. Capacity = ·86 m.f. per mile.
Sec. = ·15 □ „

(1) [1] Energy measured by variation of input into direct-current motor driving alternator, deducting C^2R losses in motor and alternator.

∿ Alternator.	Volts.	Volts × Amperes.	K. of Cables.	Length in Miles.	Ratio of observed cap. cur. to calculated cur.	Cos φ watts V × A	Watts lost per mile on open circuit.
100 B.T.H. K.W. Single Phase 100	2,000	46,000	8·6	10	2·1	·069	315

(2) [2] (*Tests taken by Dr. Mather*) Ganz Wattmeter from transformer Fed from net work at substation, ten miles from station.

99 Mordey K.W. Single Phase 150	2,240	15,500	4·72	5½	1·03	·034	97

(3) Original test taken 11 months ago. Energy measured by Schallenberger Wattmeter.

100 Mordey K.W. Single Phase 150	2,040	12,300	4·72	5½	1·02	·124	275

[1] Motor generator tests are mean of several observations.
[2] Three sets of tests taken :—
(*a*) Watts measured on cable alone.
(*b*) „ „ „ and "Ironless" choker, placed across cable ends.
(*c*) Watts measured on cable alone in series with same choker.

(4) Motor and generator. Same as No. 1. Minimum observation. Mr. Sparks.

50	B.T.H. K.W. Per Phase 2-Phase 50	2,000	11,800	8·6	10	1·16	·04	47

(5) Same as (1).

50	B.T.H.	2,000	Maximum observation.	·065	77

Dr. J. A. Fleming: Mr. Mordey has given us a plenitude of material to discuss. At this late hour of the evening, I will only touch upon one point which is one of the principal ones in his paper, viz., the measurement of the dielectric losses in a cable. Mr. Mordey tells us that his experiments showed that the true losses in 5¼ miles of a certain india-rubber insulated cable was about 2 H.P., and that the power-factor was about ·12, or 12 per cent., and these measurements, he said, were made with a recording wattmeter. He gives us no details of the experiments which he undertook to ascertain the correctness of this wattmeter. He simply says it was tested on a circuit of low power and found to be correct. I might remind him that ten years ago in this room, I brought before this Institution a Paper in which a number of measurements were recorded, taken on the Ferranti cables which had just then been laid. We were at that time interested in the large capacity current of these cables, and this current was found to be something like 44 or 45 amperes at a pressure of 10,000 volts. This corresponds to about 600 apparent H.P. The chief thing which concerned those who were connected at that time with the London Electric Supply Corporation was how much of this apparent 600 H.P. was real horse power. In those days I had not any wattmeter which would deal with these large pressures, but I remember that Mr. d'Alton, who was then the engineer-in-chief of the Corporation, attacked the problem in a very practical manner. He took one of the day-load engines at Deptford coupled to a 300 H.P. alternator, and he ran it empty and took very careful indicator friction diagrams. Then he switched on to the alternator the Ferranti cables one by one, taking diagrams in between each connection, and in that way he found that the real power taken up in the dielectric of these four Ferranti cables was about 10 or 12 H.P. I have not been able to lay my hands on the exact figures of observation, but I think I can trust my memory in this respect. One thing I am absolutely certain of is that the power-factor of these cables was not so large as 12 per cent. The power-factor we found for these cables was ·02 or 2 per cent., which confirms the figures which have been given by Mr. Sparks for certain other dielectrics. If it had been 12 per cent., or anything like the figure Mr. Mordey gives, it would have meant that 50 or 60 real H.P. were taken up in the Ferranti cables, and that certainly was not

Dr. Fleming. the case. Then comes the question: Is that difference due to the nature of the dielectrics—paper in our case as compared with the india-rubber in Mr. Mordey's—or is it due to an error in measurement? Has Mr. Mordey been misled by his wattmeter? Mr. Mordey will remember that some six or eight years ago, or rather more, we were very much concerned in discussing the advantages of open and closed magnetic circuit transformers: and that after the question had been battled for a long time between Mr. Mordey and Mr. Swinburne and others, it was agreed that each of them should put a transformer into my hands to be tested and that I should act in some sort as an umpire between the two. Mr. Mordey sent me a closed iron circuit transformer, and Mr. Swinburne sent an open iron circuit one. Mr. Swinburne was so kind as to send with his transformer a wattmeter which he had made for the purpose. It was a harmless looking instrument, but nevertheless a miracle of ingenuity, for whilst it measured perfectly correctly, when applied to measure the iron loss in Mr. Mordey's transformer, yet when applied in the same way to measure Mr. Swinburne's own transformer, its indications were too small by 50 per cent. I never felt a higher appreciation of Mr. Swinburne's ingenuity than I did on that occasion. But more, the very same wattmeter was applied to test the dielectric loss in a condenser which Mr. Swinburne also sent me, because he was very much interested at that time in employing condensers to neutralise the large magnetising current of open circuit transformers. When, however, his wattmeter was applied to measure the dielectric loss in this condenser, it was found to measure 300 per cent. too much. We had some little discussion here as to the causes of these deficiencies and of that remarkable performance, and I think it was Dr. Sumpner who pointed out from the figures of observation that I gave that it could be accounted for by the eddy currents set up in the metallic parts of the wattmeter construction, and that if these were prevented the instrumental error was removed. Ever since that time I have made wattmeters in which I have not used any metal parts. Such an instrument is more reliable than the usual productions of the instrument maker. I suggest to Mr. Mordey that he should re-examine this question with the aid of another wattmeter, and, in view of the great difficulties which occur in using a dynamometer wattmeter, on circuits of small power-factor, I think it would be desirable to employ a confirmatory method of a kind which I have used with some success. Let him take a continuous-current motor and put on to the shaft a couple of slip-rings, and provide those with brushes so as to be able to draw off from the armature of the motor a single-phase alternating current: Run that motor empty from a secondary battery and he can measure the power put into it by a potentiometer with any degree of accuracy he pleases. Then if we connect the two brushes to the copper circuits of the cable to be tested and any true power is taken up in its dielectric, it must show itself on the continuous-current side of the motor by an increased power absorption, and you can make the measurement of the true dielectric loss in that cable with very little trouble and with a great degree of accuracy by measuring the increased power absorption on the continuous-current side. That is practically

only a refinement of the method which Mr. d'Alton employed many years ago at Deptford to ascertain for himself as a practical engineer the real losses in the Ferranti cables. Dr. Fleming.

With regard to Mr. Mordey's wattmeter, perhaps I may be allowed to say one word before sitting down. Mr. Mordey has constructed a wattmeter in which he makes one circuit do duty as the secondary circuit of the auxiliary transformer and the movable part of the wattmeter. He gets rid in this way of the mercury contacts, but I must say that I do not see that this is any very great advantage. It has one great disadvantage over the method which I suggested eight years ago of using the auxiliary transformer separately, and that is you have no means of ascertaining, by any experiments, precisely what is the phase of the current in the movable circuit as compared with that of the impressed E.M.F. on the primary terminals of the transformer. A very little difference of phase in these two quantities affects very much the wattmeter reading when operating on a power-absorbing circuit of low power-factor. Take, for instance, Mr. Mordey's own case. He tells us that his own wattmeter showed a power-factor of 0·12. If that figure is correct, it shows that the current was about 83° in advance of the E.M.F., and he found 2 H.P. taken up in the cable. If his current had been 90° in advance of his E.M.F., it would have indicated that no power was being taken up in the dielectric. Hence this inferred loss of 2 H.P. depends entirely on the accuracy of this difference of phase of 7°, and he does not give us in his paper any proof that that wattmeter was absolutely correct to that extent. If the phase difference, for instance, had been but 3½° instead of 7°, the power absorption would have been 1 H.P. and not 2 H.P. Therefore, I think it is advisable in all these measurements of power absorption in circuits of small power-factor to check these determinations by the wattmeter by some other direct method, such as I have suggested.

Dr. W. E. Sumpner: Mr. Mordey's paper has given rise to many interesting points, but I will confine myself to two. One is the power-factor which Mr. Mordey has alluded to; the other is a factor which Mr. Mordey has left out of account, and which, I think, is of equal importance with the power-factor in determining what his paper is intended to bring before us—namely, the relative importance of the losses which go on in the cable. Mr. Mordey has given us a number of figures which give the number of watts supposed to be lost in the cable under certain circumstances; but none of these numbers have been compared with the really important matter about the cable—namely, the load that that cable is intended to transmit. There are two factors which determine the percentage which the loss in the cable bears to the load which the cable transmits. One is the power-factor, and the other is the ratio of the capacity-current to the load-current. Mr. Mordey in no part of his paper has referred to the load-current, or to the proportion which the capacity-current bears to that load-current. If, for instance, the capacity-current is half the load-current, and if Mr. Mordey's power-factor is correct, the loss in the cable is 6 per cent. of the load. If, however, the capacity-current is one-tenth of that load-current, then, supposing Mr. Mordey's power-factor is true, the loss in the dielectric Dr. Sumpner.

Dr. Sumpner.

is only 1·2 per cent. Now what is that proportion? The proportion depends upon something which Mr. Mordey has alluded to, but which he has given no precise information about—namely, the percentage drop in volts which is allowable in the line. What is that percentage drop of volts? I ask you to assume that the drop in the line is 4 per cent. I take that figure because I know as a fact that that was the percentage loss in the cable at Deptford ten years ago. Take, therefore, the case Mr. Mordey has mentioned, of 5½ miles of 37/15 cable, run at 6,000 volts, and 50 periods. Under these conditions the capacity-current works out at 9 amperes. The load-current comes out at 77 amperes, and the current density is less than 500 amperes per square inch. The load-current is 77 amperes as compared with a capacity-current of 9 amperes. That is to say, the load-current is more than eight times the capacity-current. If Mr. Mordey's power-factor is correct, the loss in the dielectric is only 1½ per cent. of the full load; or if what I consider the power-factor is correct—namely, the number which Dr. Fleming has mentioned, ·02—the loss in the cable is only ¼ per cent. of the full load. That is to say, the cable can be run for sixteen hours at the full voltage without losing more energy than would correspond with the heating of the copper in one hour at full-load. This ratio of capacity-current to load-current is a factor which Mr. Mordey has entirely left out of his paper, and which I contend is a factor just as important as the power-factor in determining the importance of this dielectric loss.

There are other matters in reference to the choker device which I should like to allude to if I had time. Mr. Mordey has not referred at all to the loss in the choker; he has not compared it with the loss in the line. If you take the power-factors which I believe to be correct—2 per cent. for the line and 4 per cent. or 6 per cent. for the choker—the power-loss in the choker is two or three times the power-loss in the line, so that if the power-loss in the dielectric is important, the power-loss in the choker is still more important.

I pass on to consider the matter of the power-factor. Mr. Mordey has given us a number for it higher than anybody else has ever obtained, and which is quite at variance with the numbers which have been published. I need not quote them. Dr. Fleming has already mentioned his measurement of ·02, which coincides with my own results and with those of Professor Ayrton. I have not had an opportunity of testing long lengths of cable, but I have tested a large number of condensers at various times during the last twelve years, and have always found the power-factor to lie between ·025 and ·015. In the large majority of cases a figure close to ·02 was obtained. How, then, is it that Mr. Mordey has got his very high results? I can suggest several possible explanations. I cannot pretend to show the reason, because Mr. Mordey has given us no particulars of the conditions of the test. But there are two points in the paper on which I should like Mr. Mordey to give us information in his reply. He says on p. 372 that the wattmeter he used for testing this cable had been specially tested on a circuit of low power-factor. I am not going to dispute that at all, but I wish to know whether the circuit on which the calibration was made took a leading, or a lagging current, and how the power-factor was tested independently of the watt-

Dr. Sumpner.

meter under test. The point I wish to make is this, that it is quite possible for a wattmeter to measure fairly accurately on a circuit of low power-factor, say ·02, if the circuit on which it is tested carries a lagging current; and yet the same wattmeter may read absolutely wrongly, and even negatively, when the circuit takes a current of the same power-factor, but a leading current instead of a lagging one. I do not think it has been noticed before that it is easily possible for a wattmeter to read negative on a condenser circuit. It is a fact that can be easily explained when the low power-factor of the condenser is taken into account. If a condenser has a power-factor of only ·02, it means that the phase difference between the pressure-current and the load-current is 88·6°. Thus the phase difference falls short of 90° by only 1° or 1½°. If, therefore, the lag in the pressure-coil is more than 1½°—and that is a very small amount—the phase difference would not only reach 90°, which would reduce the deflection to zero, but it would be actually more than 90°, so that the wattmeter would read negatively. This is not a merely theoretical point: I have tested it experimentally. I applied an alternating voltage to a condenser through a wattmeter and obtained a certain reading for the power. I then inserted a very small amount of self-induction into the pressure-coil, and the reading was reversed in direction. Now is there anything in Mr. Mordey's conditions of test which would produce a lag of 1½° or more? I think Mr. Mordey must have had in his circuit something which did that. I believe he must have had a transformer in connection with his wattmeter. At all events, I should like him to mention in his reply whether he used a transformer or not. If you use a transformer the assumption usually made, that the voltages of the primary and secondary circuits are in the same phase, is only approximately true. It is true enough for the ordinary circumstances under which a transformer is used, but there is always a difference in phase of something like 4 or 5 degrees between the two voltages, and if the load-currents are anything like the normal load-currents in the transformer, the phase difference may be considerably greater. That phase difference may produce some very extraordinary results when the converter is used for tests depending on phase. I have tried it experimentally for the sake of bringing the matter before this Institution. I have tested a condenser whose power-factor I perfectly well knew, by means of a wattmeter to which a transformer was attached. My transformer was not a toy transformer, as in Mr. Mordey's wattmeter. I used one of a commercial size and of good make, and not having more magnetic leakage than is usually found in transformers of good make. It was of 3-unit capacity, and very under-loaded. I used it under what I may call normal conditions, the full voltage on the coils, and with small currents through them. I also experimented with it under abnormal conditions, with low voltages on the coils, and currents comparable with, but less than, the full-load currents, conditions under which these effects would be abnormally large. This is the kind of result which can be obtained. The effect on the reading will depend upon the way the transformer is connected up, whether it is used in the pressure-circuit, or in the current circuit. The effect may be to increase or to decrease the reading. It may make it negative or positive. Taking

Dr. Sumpner.

a condenser whose power-factor I knew was ·62, I have obtained with one arrangement power-factors from +·02 to +·06, and also up to +·4. With another arrangement I have obtained negative power-factors of —·007 and —·44. If the wattmeter has its constant determined from the simultaneous readings of an ammeter and voltmeter on a non-inductive circuit, the wattmeter constant, if used with a transformer, will be wrong, owing to the influence of the leakage of the transformer. With a constant determined in this way it is possible to get apparently a negative power-factor for a condenser of —1·6—a result which is altogether impossible and absurd, but which is only absurd owing to the assumption made in the test that the transformer voltages are in the same phase. I do not wish to dwell upon the subject; but just with reference to Mr. Mordey's wattmeter I should like to say that I imagine the difference in phase produced by the toy transformer would be serious, and I really believe that if that wattmeter is used to test a condenser or cable the result will appear to indicate that the cable generates power instead of absorbing it. There is sufficient evidence in Mr. Mordey's paper to show that the instrument is erroneous. He points out that its constant depends on frequency. Now its constant can only depend on frequency owing to the fact that the lag in the pressure-coil influences the reading. If this is so the constant will alter not only for frequency, but also for the power-factor of the circuit under test. This means that the instrument can be used to measure what you already know, but not to measure what you do not know.

[*Communicated, February 21st*]: The error in a wattmeter due to inductance in the pressure circuit can be expressed by a simple formula when this inductance and the power-factor of the circuit tested are both small quantities.

If f is the power-factor of the circuit tested (assumed to take a leading current), and if a refers to the pressure-coil and is the quantity usually denoted by the formula—

$$\frac{Lp}{R} = a,$$

where L/R is the time constant of the pressure-coil, and $p = 2\pi n$ where n is the frequency (more generally a is the tangent of the angle representing the phase difference between the current in the pressure-coil and the voltage it is supposed to indicate) it will be found that—

$$\frac{\text{actual reading of wattmeter}}{\text{true reading of wattmeter}} = \frac{f-a}{f} = 1 - \frac{a}{f}.$$

It follows that if $f = {}$·02 and a is greater than f the reading will be negative. Also if the reading is negative f must be less than a. Moreover as a alters with frequency, being proportional to n, the correcting factor of the wattmeter must also alter with n. It also alters with f. The time constant of the pressure-coil of a wattmeter may easily exceed ·0001; and as p, when the current frequency is 50, is 314, it follows that a may easily exceed ·03 or be greater than f for a condenser circuit.

Mr. Swinburne.

Mr. J. SWINBURNE: There are four main points in Mr. Mordey's paper: arranging choking coils to take up the capacity-current of

cables; measuring capacity in terms of pressure frequency and current; importance of loss of power by dielectric hysteresis; and a form of wattmeter. Mr. Swinburne

As regards the placing of choking coils and condensers in parallel, the scientific, or elementary trigonometric knowledge was quite old. The idea is also old in a way as a piece of practical engineering. Condensers were sold to take up the wattless currents of Hedgehog transformers. Mr. Mordey has himself dug up a testing arrangement at the Silvertown works. This was supplied about ten years ago, and consists of two transformers giving 40,000 volts and 3 amperes, supplied by a 30,000 watt dynamo. There are two choking coils made adjustable, taking up to about 100,000 apparent watts. I had completely forgotten all about designing these until Mr. Mordey told me about them. But, in spite of these things, I think that Mr. Mordey has brought forward an arrangement which is new to most of us, though a rigid search would have unearthed primitive users. There is generally no difficulty in finding earlier examples of anything, but the device has to be re-invented before you can begin to make the search for prehistoric examples. As a matter of fact, there was a period of alternating current inventive activity about ten years ago, and much of what was done then is now buried, as it is never read, and is not, therefore, public knowledge. It requires nearly as much ability, and, in some cases, just as much, to re-invent a device as to invent it for the first time. Apparently there were many cases where the capacity current was a difficulty. Those who had to deal with it did not know what to do, and those who did know what to do did not exist, or were not there; and Mr. Mordey stepped forward and solved the difficulty.

Measuring capacity in terms of pressure, current, and frequency, is an old practice, but a practice that has been largely forgotten. My condensers in old days were all labelled in current. Though Professor Ayrton may have asked for his condensers to be graduated in this way, our practice was not the result of his suggestion. It was always the practice, and all the condensers were marked in current. The method is none the worse for being suggested by Professor Ayrton. As engineers measured the idle current of the Hedgehog transformers in amperes, it seemed the obvious thing to mark the corresponding condensers in amperes. This practice has died out, and, though a condenser cannot be accurately marked in amperes, as a rough method it is good, and, though he now disclaims it, I think Mr. Mordey did well in calling attention to it.

The loss of power by dielectric hysteresis, or whatever we like to call it, is a matter of the gravest consequence. Whether Mr. Mordey has measured it incorrectly or not I have no idea; neither do I think it matters very much, unless his measurements are so very erroneous that there is no really important waste of power in the dielectric. As the waste of power is going on always, it is a serious matter, even if small in comparison with the full load copper loss of the cable. This dielectric loss will vary enormously in different cables. Not only will rubber differ largely from paper or oil cables, but most likely different cables of the same make, and perhaps even different lengths of the

Mr. Swinburne.

same cable will vary considerably. Temperature will also probably affect the loss greatly in a given case. That may, to some extent, account for the discrepancy between Professor Ayrton's and Mr. Mordey's figures, though it can hardly account for the whole difference. The term dielectric hysteresis has been applied a little rashly. If Maxwell's suggestion is at all near the truth the term is misapplied, and the loss is purely due to C^2R. For example, condensers in series with resistances, or condensers in series with some of them shunted by resistances, would show apparent dielectric hysteresis. Again, the insulators that heat most are those whose specific inductive capacities are abnormally high in relation to their refractive indices, and this would tend to show there is, so to speak, molecular conduction, or little-resistant paths of lengths of the order of the dimensions of molecules. It is probable that, if there is a demand for cables with low dielectric losses, such cables can be made. The power-factor of the condensers made at Teddington was much lower than the figure given by Professor Ayrton. It is quite possible they may have deteriorated in ten years; that is more likely to be the solution than that Professor Ayrton's measurements are wrong.

A wattmeter must be specially well designed to test loss in dielectrics. The simplest way of checking them is with a two-phase dynamo. A resistance load is put on each circuit, and the wattmeter circuits changed over so as to get two readings, so as to get the error due to the wattmeter in one direction, while the error due to want of symmetry of the dynamo cancels out. When I made things I made wattmeters, and they were checked with an old Gramme Jablochkoff machine. In spite of that Dr. Fleming's indictment is true. It was not a question of fiendish ingenuity on my part though. The instrument was designed all right, and the main coils were carried by two insulated brass pillars. The works saw no reason for insulating one end of these pillars, and removed the insulation. Hence the accusation of crime. How many wattmeters were sent out like this I do not know. The resistance to be used in series with the pressure coil is most important. We wound them with a single wire, reversing the bobbin in the lathe after each layer. This avoids self-induction, capacity, and leakage errors, and is much better than double-winding. Mr. Duddell finds that one of these bobbins is faulty, and apparently sparks inside. Whether that is a fault in make-up or an error in design I do not know, as I have not examined the coil. It is probably a fault in make up of the particular coil; but, in any case, Mr. Duddell's observation is important.

As to the particular wattmeters used in Mr. Mordey's experiments, there is no very clear account given. Mr. Baillie pointed out to me some time ago that self-induction, the ordinary error of a wattmeter, diminishes the reading on a condenser, unless it is so great as to cause the instrument to read negative watts.

Mr. Mather.

Mr. T. MATHER: Mr. Mordey's paper has been useful in drawing attention to the importance of Dielectric Hysteresis losses in concentric cables. There are, however, several points in his paper which cannot pass without criticism. The chief of these points is that *a concentric cable absorbs a considerable amount of power when subjected to high*

alternating pressures, and since nearly half the paper is based upon this *alleged* fact, it demands first place in the discussion. Mr. Mather.

I may preface my comments by saying that to avoid ambiguity I shall use the expression "volt-amperes" instead of "apparent watts," and restrict the word "watts" to *real* power.

Mr. Mordey says that cables have power-factors as high as 0·124, *i.e.*, they waste, at light load, about ⅛th the volt-amperes supplied to them.

It should be noted that this number is the result of a single experiment on a single cable, and does not seem to have been repeated or checked by any independent method, and yet Mr. Mordey bases half his paper on it and works out tables of losses for cables of various capacities working at various voltages as if his power-factor 0·124 was like the "laws of the Medes and Persians." That this value 0·124 is far above the average is conclusively seen from the numbers given below in Table I.

The loss found by Mr. Mordey is so large that it would have been quite easy to measure it in several well-known ways, and in my opinion the high figures should not have been published until there was no doubt whatever about their substantial accuracy. For in effect Mr. Mordey's result condemns cables for high pressure alternate current working on the uncorroborated evidence of a single specimen. How would Mr. Mordey like all his alternators condemned because the tests on a particular alternator of some other make showed, or seemed to show, it to be a very poor one?

For, even if we grant the loss mentioned by Mr. Mordey for the particular cable, it would still have been desirable to test many other cables before drawing generalised conclusions intended to apply to *all* cables.

Ordinary wattmeters, and especially so-called "recording wattmeters," are very inaccurate at low power-factors unless special precautions are taken to ensure the current in the pressure coil being strictly in phase with the applied P.D., so that Mr. Mordey's method of measuring the loss, even though his meter, as he asserts, had been tested at low power-factors, was not a very fortunate one.

A convenient method of measuring dielectric losses is to use an "*ironless*" choker of inductance suitable for bringing the current in, or nearly in, phase with the alternator P.D., and using a moderately good wattmeter to measure the power in cable and choker. The loss in an "*ironless*" choker wound with thin wire can be found very closely by C^2R, and the differences between C^2R and wattmeter reading gives the loss in the cable. Two arrangements are possible :—

(1) *Cable and Choker in parallel* (Fig. B).—An "ironless" choker being used, as suggested by Professor Ayrton in *The Electrician* of January 18th. In this case a wattmeter suitable for high P.D.s must be used and the current coil of the instrument placed in the alternator circuit.

(2) *Cable and Choker in series* (Fig. C), as suggested by me in the *Electrician* of January 25th. Here a wattmeter suitable for low pressures will suffice and only a *low* P.D. is required. As the alternator, cable, and choker are in series, the circuit is perfectly simple. The current

Mr. Mather. coil of the wattmeter is, of course, included in the same circuit, and the pressure coil connected with the alternator terminals.

NOTE.—Since the above was written Mr. Campbell has called my attention to the fact that these methods were used by Messrs. Rosa and Smith in measuring dielectric hysteresis losses in condensers. See *Physical Review*, vol. 8, pp. 1–20. 1899. T. M.

In either arrangement it is desirable to use *electrostatic* voltmeters to show the pressure to which the cable is subjected. Results taken by these two methods as well as by measurements on the cable only are given in Table I. These numbers have been obtained by Professor Ayrton and myself, assisted by Messrs. Caine, Denton, Henry, and Mair, students of the Central Technical College, to whom our best thanks are tendered. Each value of the power-factor thus given is the mean of a large number of consistent observations, and obtained in some cases in totally different ways. There is therefore no doubt whatever as to the substantial accuracy of the results.

TABLE I. (*Mather.*)

DIELECTRIC HYSTERESIS LOSSES OF LONG CABLES.

Material.	P.D. in Volts.	Fre-quency.	Power Factor.	Maker.
Oiled Paper* ...	2,017	100	0·024†	British Insulated Wire Co.
Jute	2,030	71·5	0·027	Callender & Co.
India Rubber ...	2,000	105	0·028	Silvertown Co.
India Rubber, County of London Cable	2,230	100	0·029†	„ „

MR. MORDEY'S EXPERIMENTS.

India Rubber, County of London Cable	2040	100	0·124	Silvertown Co.

It is significant to notice that, according to these results, Mr. Mordey's tests on the County of London Cable gave *a power-factor more than 400 per cent. too high.*

The figure 0·029 obtained in our tests on the same cable is the mean of sixteen separate experiments made in the three different ways shown in Figs. B, C, and D, none of which differed from the mean 0·029 by more than 1 in the third decimal place. Hence it seems to us that Mr. Mordey's results are very inaccurate, and should not be applied in any case.

Turning now to the secondary parts of the paper, I may remark that there is no novelty in measuring capacities by alternating currents

* Low pressure cables tested at over 2,000 volts.
† Tested in three different ways with very accordant results.

as described on page 366, nor in supplying the "idle" currents of cables by inductive coils or chokers (pages 377 and 378). Both have been common knowledge for the past ten years. Mr. Mather.

Mr. Mordey's treatment of capacity measurements is very unequal in the detail given. For example on page 365 he tells "engineers who have not hitherto considered the subject," that the unit of capacity is

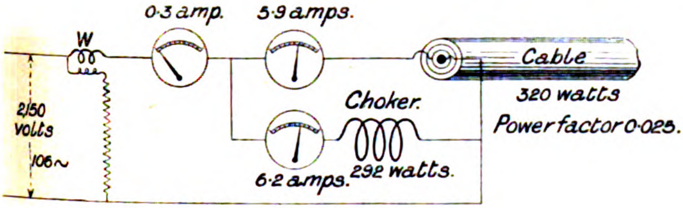


FIG. B.

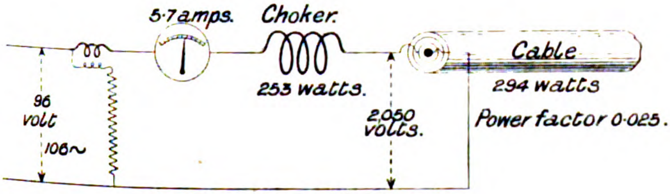


FIG. C.

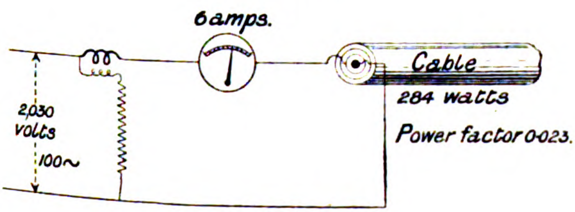


FIG. D.

the farad, and that it is too large for practical purposes. He then states that "the charging current for a cable is easily found if we know the capacity of the cable," and gives the formula,

$$\text{Charging current in amperes} = \frac{\text{volts} \times \text{periods per second} \times \text{microfarads} \times 2\pi}{1{,}000{,}000.}$$

No caution appeared in the slip proof given out at the meeting (except the obscure note on page 379) to remind these engineers that the current taken by a cable depends very largely on the *wave form of the alternator* and on the load under which the machine is working.

Then followed the statement that *one microfarad takes 0·6283 amperes at 2,000 volts 50* ∿ and a suggestion that station engineers should have ammeters graduated in microfarads. From the remarks with which Mr. Mordey prefaced the adjourned discussion, it is evident that since the reading of his paper on the 10th of January he has found out

Mr. Mather. coil of the wattmeter is, of course, included in the same circuit, and the pressure coil connected with the alternator terminals.

NOTE.—Since the above was written Mr. Campbell has called my attention to the fact that these methods were used by Messrs. Rosa and Smith in measuring dielectric hysteresis losses in condensers. See *Physical Review*, vol. 8, pp. 1–20. 1899. T. M.

In either arrangement it is desirable to use *electrostatic* voltmeters to show the pressure to which the cable is subjected. Results taken by these two methods as well as by measurements on the cable only are given in Table I. These numbers have been obtained by Professor Ayrton and myself, assisted by Messrs. Caine, Denton, Henry, and Mair, students of the Central Technical College, to whom our best thanks are tendered. Each value of the power-factor thus given is the mean of a large number of consistent observations, and obtained in some cases in totally different ways. There is therefore no doubt whatever as to the substantial accuracy of the results.

TABLE I. (*Mather.*)

DIELECTRIC HYSTERESIS LOSSES OF LONG CABLES.

Material.	P.D. in Volts.	Frequency.	Power Factor.	Maker.
Oiled Paper* ...	2,017	100	0·024†	British Insulated Wire Co.
Jute	2,030	71·5	0·027	Callender & Co.
India Rubber ...	2,000	105	0·028	Silvertown Co.
India Rubber, County of London Cable	2,230	100	0·029†	" "

MR. MORDEY'S EXPERIMENTS.

India Rubber, County of London Cable	2040	100	0·124	Silvertown Co.

It is significant to notice that, according to these results, Mr. Mordey's tests on the County of London Cable gave *a power-factor more than 400 per cent. too high.*

The figure 0·029 obtained in our tests on the same cable is the mean of sixteen separate experiments made in the three different ways shown in Figs. B, C, and D, none of which differed from the mean 0·029 by more than 1 in the third decimal place. Hence it seems to us that Mr. Mordey's results are very inaccurate, and should not be applied in any case.

Turning now to the secondary parts of the paper, I may remark that there is no novelty in measuring capacities by alternating currents,

* Low pressure cables tested at over 2,000 volts.

† Tested in three different ways with very accordant results.

as described on page 366, nor in supplying the "idle" currents of cables by inductive coils or chokers (pages 377 and 378). Both have been common knowledge for the past ten years. Mr. Mather.

Mr. Mordey's treatment of capacity measurements is very unequal in the detail given. For example on page 365 he tells "engineers who have not hitherto considered the subject," that the unit of capacity is

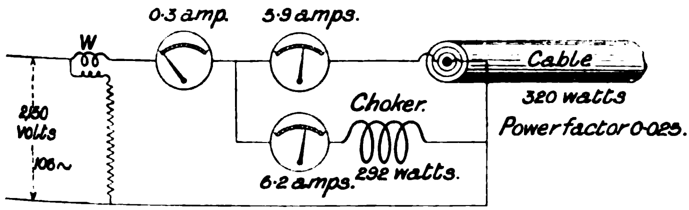


FIG. B.

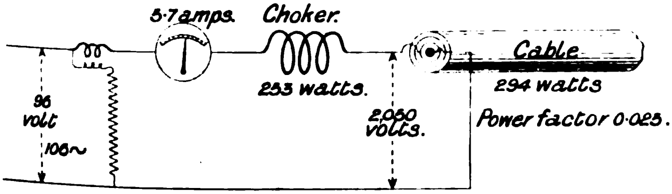


FIG. C.

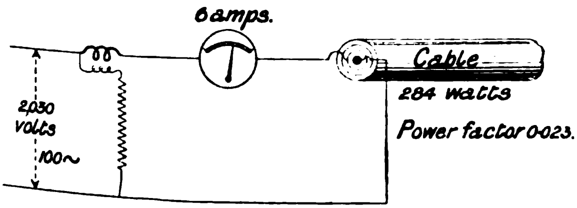


FIG. D.

the farad, and that it is too large for practical purposes. He then states that "the charging current for a cable is easily found if we know the capacity of the cable," and gives the formula,

$$\text{Charging current in amperes} = \frac{\text{volts} \times \text{periods per second} \times \text{microfarads} \times 2\pi}{1{,}000{,}000}.$$

No caution appeared in the slip proof given out at the meeting (except the obscure note on page 379) to remind these engineers that the current taken by a cable depends very largely on the *wave form of the alternator* and on the load under which the machine is working.

Then followed the statement that *one microfarad takes 0·6283 amperes at 2,000 volts 50* ∿ and a suggestion that station engineers should have ammeters graduated in microfarads. From the remarks with which Mr. Mordey prefaced the adjourned discussion, it is evident that since the reading of his paper on the 10th of January he has found out

Mr. Mather. how misleading this method for measuring capacity may be, for he now acknowledges that errors of two or three hundred per cent. may arise.

How puzzled the poor engineer, who requires to be told about the unit of capacity, would be, in making capacity measurements by such a method, to find that a particular cable had all sorts of capacities depending on the time of day at which his measurements were taken! For (as Dr. Fleming has well shown in the case of the large alternators belonging to the City of London Company) the wave-form of the pressure supplied depends on which alternators are being used, and on the load under which they are working.

The differences in capacity-current as dependent on wave-form is well illustrated by the results shown in Tables II. and III., which were taken on condensers of some 50 microfarads.

TABLE II. (*Mather.*)

CAPACITY CURRENTS AS INFLUENCED BY WAVE-FORM.

Machine used.	Frequency n	Current at 100 Volts. A.	Capacity from $F = \frac{A \times 10^6}{2 \pi n V}$ microfarads.	True capacity in microfarads.
Ferranti Alternator... ...	100	3·0 amps.	47·8	49·4
Pyke and Harris Alternator	100	4·6 "	73·2	"
Wenstrom Converter ...	43	1·18 "	43·7	"
" " ...	58	1·69 "*	46·5	"
Gramme " ...	25	0·7 "	44·5	"

NOTE.—The Ferranti alternator has an E.M.F. wave nearly of sine form, whilst the Pyke and Harris machine has an E.M.F. wave very peaked.

TABLE III. (*Mather.*)

EFFECT OF LOAD ON CAPACITY CURRENTS.

Pyke and Harris 6-KW. Alternator, run at constant speed and constant P.D.

Frequency n.	Load-current in amperes at 100 volts.	Capacity-current at 100 volts. A.	Capacity calculated from $F = \frac{A \times 10^6}{2 \pi n V}$ microfarads.	True capacity in microfarads.
100	0	4·6	73·2	
"	0·6	4·5	71·6	49·4
"	1·2	4·35	69·3	"
"	3·5	3·95	62·9	"
"	7·0	3·6	57·3	"
"	13·5	3·3	52·5	"
"	30	3·2	50·9	"

* Machine sparking a little at commutator.

These tables show capacities differing by 58 per cent. according to the alternator used (Table II.), and with the same alternator differently loaded by putting lamps in parallel with the condensers, a change of nearly 50 per cent (Table III.). These are by no means extreme cases. Mr. Mather.

In connection with the effect of wave form on the supplying of capacity current by chokers, I may mention that with the first method used at Prescot, on Tuesday last (see Fig. B), when the choker and cable were in parallel and the pressure supplied direct from the machine, we could not reduce the alternator current below 3 amperes when about 6 amperes went through the coil and about 6 amperes into the cable, no matter at what frequency the alternator was run, the machine being a Mordey's so-called "sine wave" alternator. But when the 2,000 volts supplied by the alternator was first transformed down to 100, and then up again to 2,000, and a choker also inserted, the current supplied to the arrangement shown in Fig. B went down to about 0·3 amperes at 106 $\sim$. Hence it seemed that the Mordey alternator did not give a pure sine wave, and it was necessary to insert the transformers and choker to reduce the higher harmonics. Mr. Mordey's own experiments given on page 378 of his paper point to the same conclusion.

On pages 379 and 381 the subject of chokers for supplying the idle currents to cables is dealt with, and the design of a choker given. In my opinion the use of iron in a choker for such a capacity is a mistake. The late Mr. J. E. H. Gordon in the early eighties showed, at Paddington, how *not* to make chokers; and a few years later Mr. Swinburne brought out a greatly improved choker in the shape of his Hedgehog transformer. He opened the magnetic circuit, and used only a small amount of iron; and yet Mr. Mordey now describes a choker containing a large amount of iron and a power-factor as large as 0·041 for one of 12,000 volt-ampere capacity at 100 periods. Surely this is a serious retrograde step. It is generally recognised that a closed magnetic circuit in a choker is very wasteful of power, for the power-factor is usually of the order 0·6 to 0·7 for transformers on no load. Opening the magnetic circuit, although it necessitates rather more copper, greatly reduces the power-factor, and the more open the magnetic circuit the smaller the power-factor becomes. The logical conclusion to which these considerations lead is *Remove the iron altogether, and the power-factor is reduced to a small value.* The numerical magnitude of the power-factor depends on the amount of copper put in the coil, and may, in fairly small chokers containing about 100 lbs. of copper, be reduced to about 0·02 at 100 $\sim$ and 12 to 15 thousand volt-amperes.

On the table before you is the choker that has been used in most of the tests on dielectric hysteresis recorded in Table I. It contains 81 lbs. of No. 14 copper wire, has a total weight of 92½ lbs., an inductance of 0·53 henry, and a power-factor of 0·021 when warm.

Mr. Mather.

TABLE IV. (*Mather.*)

COMPARISON OF 12,000 VOLT-AMPERE CHOKERS.

	Mr. Mordey's Choker.	"Ironless" Choker.	Ratio.
Total Weight	260 lbs.	92·5 lbs.	2·8
Weight per kilo-volt-ampere	22 ,,	7·7 ,,	2·8
Loss at 2,000 volts, 100 ∿	500 watts	250 watts	2·0
Power-factor ,, ,, ,,	0·041	0·021	1·9
Cooling surface per watt ...	1·2 sq. in.	1·7 sq. in.	0·7

A comparison of the "ironless" choker with the one described by Mr. Mordey is given in Table IV., from which it will be seen that in the ironless choker we have one of *not much more than one-third the weight of Mr. Mordey's, having half the loss, about half the power-factor, and a greater cooling surface per watt,* whilst the simplicity of construction is such that the cost must be considerably less.

In predetermining the winding, calculation gave the number of turns as 1,367, and after winding it was found that 1,348 turns gave the required inductance. You will, therefore, see that calculation, taken only to a first degree of approximation, gave a result true to within 1½ per cent.

Much more might be said on the subject of chokers of fixed and variable inductance, but these matters I hope to bring forward in a separate paper, on which I am now engaged.

My sincere thanks are hereby tendered to the following gentlemen for the facilities and assistance so kindly given :—Professor Ayrton ; Mr. Duddell; Messrs. W. and R. K. Gray, Stuart A. Russell, and Mr. Grafton, of the Silvertown Company; Messrs. T. and J. Callender, and Mr. Goodman, of the Callender Cables Company; Mr. G. H. Nisbett, of the British Insulated Wire Company ; Messrs. C. P. Sparks, J. Smout, and J. H. Butler, of the County of London Brush Company ; Messrs. W. Cramp, C. H. Hainsworth, T. L. James, W. Templeton, and T. R. Sowerbutts, my colleagues at the Central Technical College ; and Messrs. Ablett, Blennerhassett, Duncalfe, Fasola, Griffin, and Harrold, students of that Institution. My best thanks are also due to Mr. Cramp for the clear and effective way in which he communicated my remarks to the meeting.

(*Added February 23rd,* 1901). Amongst the numerical errors occurring in Mr. Mordey's paper the following may be particularly mentioned :—(*a*) At the bottom of page 372 the C^2R loss in the cable is given as 13·4 watts. Taking the data given on page 373 respecting the resistance of the cable, I calculate that the copper loss in the cable when the capacity current is 6 amperes amounts to 35·4 watts. (*b*) On page 383, after referring to the disproportionality between the large hysteresis loss and the insignificant loss due to leakage, Mr. Mordey goes on to say that the dielectric hysteresis loss is as much as the leakage loss would be if the insulation resistance between inner and outer conductors was 9,524 ohms, instead of 2,500 megohms. Surely

Mr. Mather.

the disproportionality is not *quite* so great. Mr. Mordey has in this case neglected his power-factor 0·124, for it is evident that 10,000 volts on 9,524 ohms would waste 10,500 watts, whereas the power wasted is given as 1,296 watts. The resistance corresponding with the waste 1,296 is 77,000 ohms, and not 9,524.

Further, insulation resistances are usually given after one minute's electrification; and it is well known that the insulation resistance decreases as time of electrification decreases. When subjected to alternating pressures of 50 $\sim$, the time of electrification to be considered is of the order $\frac{1}{100}$ of a second, and the insulation resistance of a 2,500 megohms cable would be considerably less at such short times of charging. Experiments made some years ago showed that rubber cables after short periods of electrification had resistances from one-third to one-fifth of their value after one minute's electrification. The disproportionality would, therefore, be more fairly expressed by, say, 600 megohms to 77,000 ohms, instead of by 2,500 megohms to 9.524 ohms.

Mr. O'Gorman.

Mr. M. O'Gorman: Whether Mr. Mordey's test or Professor Ayrton's of the energy losses on the London and County Company's cable was the more accurate cannot be in any way verified by tests on any other cable or condenser, for the following reason: The work done on any commercial dielectrics upon which any published tests or experiments which I have been able to find have been made, varies as the square of the potential difference established between the two sides of the dielectric in question.

These results have been endorsed and quoted by Steinmetz, and independently examined by Arno, Threlfall, J. Sahulka (Wiener Sitz Ber. vol. 102), and recently quoted by Dr. De Hoor in the *Electrician* of February 8th.[1]

If this is so, the energy lost depends upon the distribution of potential within the thickness of the insulation, and this in turn depends upon the grouping of the materials in the various layers of any individual cable.

Taking a 37/15, which was the size of cable Mr. Mordey tested, and giving it, for the sake of example, the subjoined arbitrarily chosen thicknesses of dielectric (rubber) we get a curve of potential which is approximately according to Fig. E for continuous and Fig. J for alternating pressures, whereas if the dielectric were perfectly homogeneous the potential would be somewhat according to Fig. F.

The gradient or slope of potential is at every point in Fig. E indicated by the height of the ordinate of Fig. G, whereas in a uniform dielectric the gradient at every point is approximately according to Fig. H for both continuous and alternating pressures. The method of obtaining these particulars and of verifying them experimentally I hope to show on a future occasion.

[1] Under the entirely uncommercial conditions of a dielectric which has been elaborately freed from air and moisture, Mr. Threlfall has succeeded in reducing the energy wasted in a condenser to a very large extent, but he has also, by making an imitation commercial dielectric with graphite and paraffin, endorsed the above contention that the energy varies as the square or 1·6th power of the E.M.F.

Mr. O'Gorman.

If we add together the work done on each element of thickness on a homogeneous cable and add together the work done on each element on the above heterogeneous cable, it will be seen that the ratio of energy lost may be as 6 to 1 in one of the above cases.

These considerations explain how it is that Professor Ayrton found

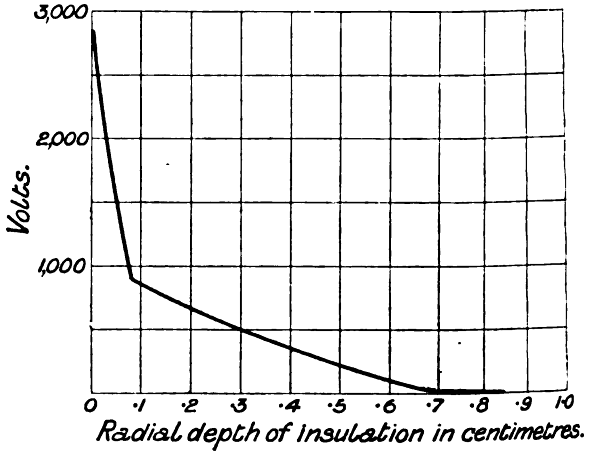


FIG. E.

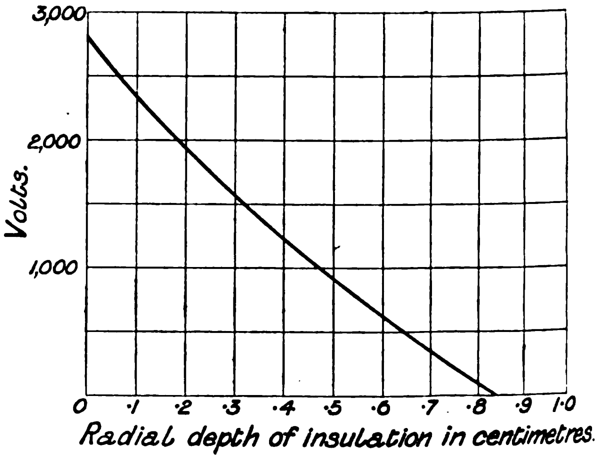


FIG. F.

power-factors for different cables varying from ·024 to ·033, and there seems no reason why the power-factor should not reach and exceed Mr. Mordey's figure in many cables which are actually in use and where no idea of such losses is entertained by their users.

These considerations also explain why the loss is greater when the curve of the alternating voltage is more peaky than a sine curve, for the

Mr. O'Gorman.

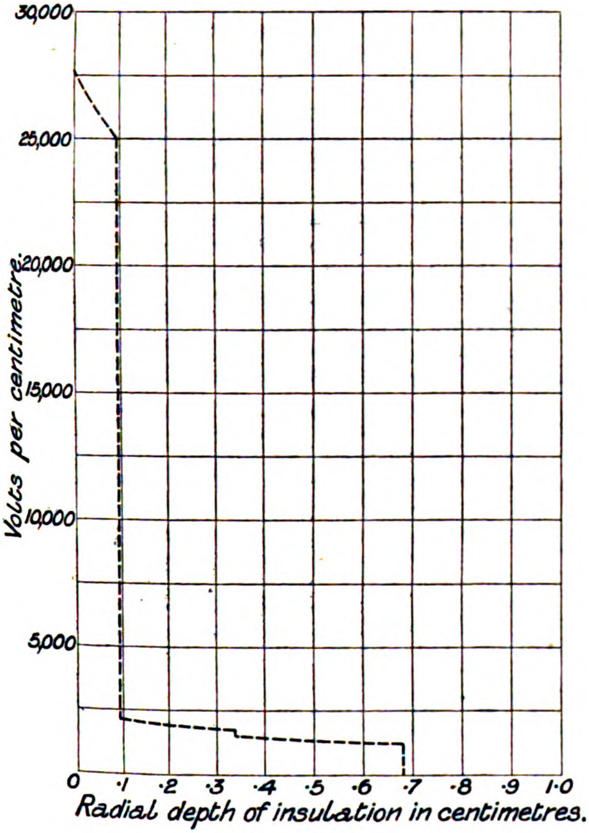


FIG. G.

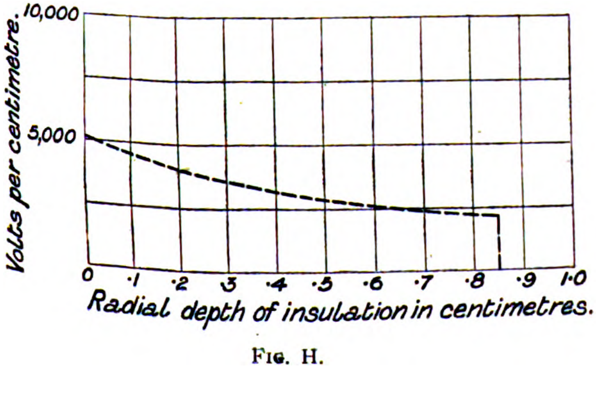


FIG. H.

Mr. O'Gorman

steepness of the gradient depends on the maximum pressure at ordinary frequencies. There is, in fact, no reason why a cable dielectric should not on some occasions actually be broken down in one layer while being perfectly sound in another. This form of breaking down would not lead to a disruptive spark right through the dielectric, but would lead to a phenomenon similar to a brush discharge from a wire in air.

When Mr. Mordey at the end of the discussion quoted Mr. Kapp as saying that certain cables that he had tested had become appreciably hot to the touch, one could not but surmise that a partial breakdown on the above suggested lines was occurring in the cables in question, and that this partial breakdown had probably occurred in the layers which were close to the lead sheath, the cable as a whole not having been raised in temperature by two or three degrees Fahr., but only the outer layers.

I would like to suggest the official abolition of the phrase "apparent

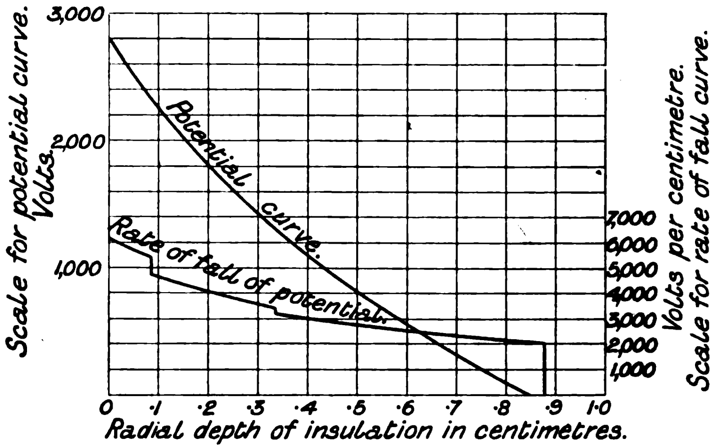


FIG. J.

watts," and the worse, because longer, phrase "phantom energy," and to suggest instead of an apparent watt not the name a "phantom erg," which it is not, but a "vamp," as an abridgment of "voltamp," which it is.

Mr. Gray.

Mr. W. E. GRAY: I have not much to say, and shall occupy little of your time. We have heard Mr. Mordey, and I, at least, have to thank him for the information he gives, by which I hope to profit considerably. Professor Ayrton and Mr. Sparks have also given us papers which are very interesting, as they appear together to summarise general knowledge up to date. There is one point on which I differ with Mr. Mordey; that is the question of capacity on a concentric cable when earthed. (In such a case I do not think the capacity of the outer can be ignored altogether, when, according to Board of Trade rules, it is earthed at one end only.) We have heard during the discussion that instrument makers do not know how to make instruments; that dynamo

makers do not know how to make dynamos to work efficiently on a distribution network; and, finally, that cable makers cannot design cables. In fact, the discussion, instead of being concentrated on the question of importance or non-importance of hysteresis, has resolved itself into a three-sided duel. I do not propose to join in this. The point I wish to speak on is that, when dealing with the question of capacity of dielectrics, little should be taken for granted, as there are many things to be borne in mind. Although in this discussion rubber and paper have been referred to as dielectrics, and a specific capacity for each has been quoted, this is not necessarily correct; indeed, it varies very considerably according to the different processes adopted in manufacture. Of this there is no doubt; consequently any statements which presuppose a definite specific capacity for india-rubber or paper as manufactured are misleading and inaccurate if too widely applied, and I think when making statements here our professors should differentiate, as the adoption of a "rule of thumb method" when dealing with such matters is not worthy of professors. In this connection I think that without going too far I could undertake, within certain limits of course, to make rubber cables of any capacity. In the same way no doubt other makers using different dielectrics could also make any reasonable variation of capacity that might be required; but it is another matter to make a cable whose specific capacity will not vary. Even in cases where the insulation resistance remains quite constant, often the capacity will vary to a considerable amount when a cable is ageing. Thus when manufactured a cable may have a specified insulation and capacity, and when tested some years after, although the insulation resistance may not have varied, the capacity in many cases will have changed considerably. It is also possible to make a cable which will not, at least for some time, vary either in insulation resistance or capacity. If an unvarying capacity is required, are engineers in central stations—those that design machinery or those that teach how to design—prepared to say what capacity is wanted to meet their requirements? Apparently not yet. With regard to dielectric hysteresis, many of those who have spoken differ entirely; even Mr. Mather differs from Professor Ayrton. Look at the results obtained when Mr. Mordey tested one form of cable and Professor Ayrton with Mr. Mather tested another form of cable. Mr. Gray.

Professor AYRTON: It was the same cable. Professor Ayrton.

Mr. W. E. GRAY: Mr. Mordey tested one form of cable; you tested another form. Mr. Gray.

Professor AYRTON: But it was the same cable. Professor Ayrton.

Mr. W. E. GRAY: I am talking in another sense. You tested at Silvertown a certain form of cable entirely different in construction from the one tested by Mr. Mordey and got totally different results, but you also got another different result when you tested the same cable as Mr. Mordey; and, in fact, your two tests on the rubber cables did not agree. How do you know that you did not make an error in your tests? Is the difference due to the fact that you did not take into consideration the fact that the forms of cable were different? Mr. Gray.

Professor AYRTON: The last one is the very cable Mr. Mordey tested. Professor Ayrton.

Mr. Gray.

Mr. GRAY: Yes; but you got a very different result from the other, and your results don't agree.

[*Communicated*]: I certainly understood that Professor Ayrton first held that the power-factor was so small as to be negligible, and Mr. Mordey pointed out that it was important. I cannot say whether or not Mr. Mordey exaggerated the importance; but, in any case, as shown by the figures given by Mr. Mather, it was not negligible. Professor Ayrton and Mr. Mather got two very different results with the same dielectric; it appeared to me, therefore, for that reason and others, that the difference might be accounted for by the difference in the forms of the cables tested by these gentlemen, the one at Streatham and the other at Silvertown.

Professor Threlfall.

Professor R. THRELFALL: Mr. Mordey has pointed out in his paper that he was able to measure the loss in a certain cable, and that loss, he says, is a dielectric hysteresial loss, on the grounds that the conductivity and leakage losses could be ascertained and allowed for, and that both these sources of loss were found to be negligible. With regard to the copper losses, no doubt Mr. Mordey is well qualified to speak, and no doubt he is also well qualified with regard to the leakage losses; but my experience of leakage losses has been that they are exceedingly subtle things. For instance, you may take a film of sulphur which is composed partly of crystallised and partly of amorphous sulphur, and you may obtain any resistance within a range of 10 to 1 according to the length of time you apply the voltage, according to the direction in which you apply the voltage, and according to the magnitude of the voltage. Therefore there is no such thing in the true ohmic sense as the resistance of sulphur, or of similar dielectrics. In short, the "resistance" of a dielectric is only definite under specified conditions of electric intensity in the dielectric, direction of that intensity, and whole previous history. It seems to me, therefore, that there is, theoretically at all events, an absolute bar to the establishment of Mr. Mordey's position as to the nature of the losses observed. I believe there has been a great deal too much readiness to talk about dielectric hysteresis. In 1892 Mr. Steinmetz, by means of a wattmeter which may or may not have been correct, measured the loss in a condenser, and he referred to this loss as due to dielectric hysteresis. Mr. Arno, an Italian who has done work on the subject, referred to the effect of dielectric hysteresis as having been established by Steinmetz. I need hardly say from what has passed this evening that it was not established at all. He might as well have deduced "original sin" as as have deduced dielectric hysteresis from the experiment from which conductance loss was not really eliminated. There is generally, and perhaps universally, a tendency to associate the heating losses in a condenser supplied with alternating currents with those phenomena which have long been known to electricians as phenomena of absorption, such as are observed when a condenser is being tested for capacity by slow-speed methods. These two causes of loss, as I was able to show in the years 1896 and 1897 (*Physical Review*, 1887), are only approximately related, at all events if the alternating current has a frequency of 30 or 40 a second. With regard to the absorption losses, so-called, $\frac{9}{10}$ths of those

are, I am perfectly certain, due to spreading over the surface of the dielectric beyond the armatures and to air discharges, as suggested by Lord Kelvin, between the armature and the dielectric surfaces. My attention was first called to this by finding that the residual charge in sulphur, in quartz, and in mica, all of which give exceedingly low residual charges, can be made to give very much lower ones by drying them over phosphorus pentoxide; and I also found, in making measurements by the rotating field method of the dielectric losses in solid dieletrics, that it was necessary to dry the specimens over phosphorus pentoxide for days before a constant result was obtained. Moreover, the method of the rotating field possesses the merit of avoiding the introduction of sharp variation in the electric force at the surface of the dielectric, such as occurs at the edge of a condenser plate, and consequently gives results which depend less on the state of the surface of the dielectric than do the usual methods. Taking all these things into account, I believe that we ought not to talk about dielectric hysteresis loss in such a case as that of the sheathing of a cable where there may be air or moisture, and where the slightest trace of air or moisture will, as Mr. Sparks has said, increase the loss to an enormous extent. If you make a condenser from which air and moisture are entirely excluded—and it may be done—then you can reduce the losses to a figure which I hardly like to mention, so small is it. It is something nearer 0·1 than 1·0 per cent., at least with a mixture of paraffin oil and vaseline. To obtain this result pure cellulose paper dried for some time at a temperature of 130 C., must be employed, and the dried paper must be further treated in the dielectric at that temperature and under a vacuum. It is the last thousandth or millionth of percentage of the air and moisture originally present that makes all the difference between whether the loss in a condenser used with alternating currents is large or small. That is a fact which I published in America and in this country, and apparently I have utterly failed to reach my audience. I do not believe there is a man in this room except myself who is aware of it. Mr. O'Gorman holds up his hand, but I cannot include even him, as he misquoted me just now. I understood him to say that the loss in a dielectric—according to me—is in proportion to the square of the electric force. Professor Threlfall.

Mr. O'GORMAN: I think you stated that to be the case in the *Physical Review* in 1897. Mr. O'Gorman.

Prof. THRELFALL: No. The losses are proportional to the internal electric force raised to some power between 1·5 and 1·9. In ordinary dielectrics the index only reaches the value of 2 when you make a dielectric purposely heterogeneous by mixing graphite in paraffin to such an extent that you probably get conductivity losses. With regard to the table which Mr. Mordey has so valorously prepared, I am afraid he is foredoomed to disappointment if he expects it to apply generally. My reason is this. I will merely mention this fact. I have taken a ladle full of melted resin and from it I have cast spheres for investigation. The spheres have been cast one after the other, the resin not even requiring to be re-heated between the separate castings; and among the spheres so cast the dielectric losses have varied by some hundred per cent. Summing up the matter we may say—(1) There is such a Professor Threlfall.

Professor Threlfall.

thing as "dielectric hysteresis," *i.e.*, when a small volume of dielectric is carried round a cycle of electric force, some of the energy of electrification is dissipated. (2) The laws connecting this dissipation with the electric force, rate of passing through the cycle, &c., are perfectly fixed and definite for each volume of dielectric. (3) It is practically impossible, however, to find or prepare two small pieces of any given dielectric which shall have even approximately the same properties in regard to the dissipation of energy. (4) The cause of the dissipation of energy is not known; but Maxwell's suggestion as to heterogeneity being possibly the cause, is shown by experiment to be most probably an insufficient explanation.

[*Communicated*]: Though properly unwilling to take up the time of the meeting with such a matter, I feel that I must add a note in regard to a criticism of a statement of mine about condenser efficiencies which has been made by Messrs. Rosa and Smith (*Phil. Mag.*, vol. xlvii. p. 19).

In the *Physical Review*, vol. iv. p. 458, and for the sake of illustration merely, I compared the efficiency of one of my specially prepared condensers with the efficiency found by Mr. Bedell and others for a waxed paper condenser. The comparison I made was based on the relative rise in temperature in the two condensers working under different but specified conditions. To make this comparison I assumed that the condensers were roughly similar both as regards capacity for heat and for electricity. Messrs. Rosa and Smith point out that unless the ratio of the thermal to the electric capacity was the same in both cases, the reasoning would be fallacious; and they then go on to show that, assuming this ratio to have the value nine in one case and one in the other, the performance of the condenser would be less satisfactory than I stated.

My reason for referring to the matter at all is that I think that anybody reading Messrs. Rosa and Smith's paper would come to the conclusion that the losses reported by me were less than they ought to have been; in fact, that I underestimated these losses, and also by implication that it is not possible to make as good a condenser as I have made. This would be a misfortune, and on this account I wish to explain how the matter really stands. I need hardly say that of course I entirely agree with Messrs. Rosa and Smith's criticism, which is perfectly just, and the cause of the misunderstanding is entirely on my side. While writing the passage in question I thought it would be interesting to make a rough comparison with the results attained by Mr. Bedell, but I certainly never expected such a comparison to carry weight. I *had measured the loss in the condenser referred to by a thermal method* very similar to the one afterwards used by Messrs. Rosa and Smith and for the same reasons, but I had not considered the matter of sufficient importance for publication. Indeed the loss was so small that my calorimetric method would have been inaccurate, and the loss was ascertained by comparing the temperature rise in the case in question with the rise under similar circumstances of a less well-made but otherwise similar instrument which had itself been subject to investigation by the calorimetrical method. The result of this comparison was to show that the condenser wasted less than 0·1 per cent. of the energy it

Professor Threlfall.

received: how much less I don't know. Now, in writing the passage which is the subject of discussion, I found that the loss roughly (and, as Messrs. Rosa and Smith show, illegitimately) deduced from the comparison with Mr. Bedell's work came out at 0·05 per cent., and, this being about the value which I already knew to be correct, I neglected to go on to state, as I ought to have done, that I had made an independent measurement. I consider it well worth knowing that it is possible by following the instructions (given in my little book on Laboratory Arts) to prepare a condenser which will not heat appreciably on alternate current circuit, even though the condenser, when tested by charges of long duration, shows the phenomena of absorption.

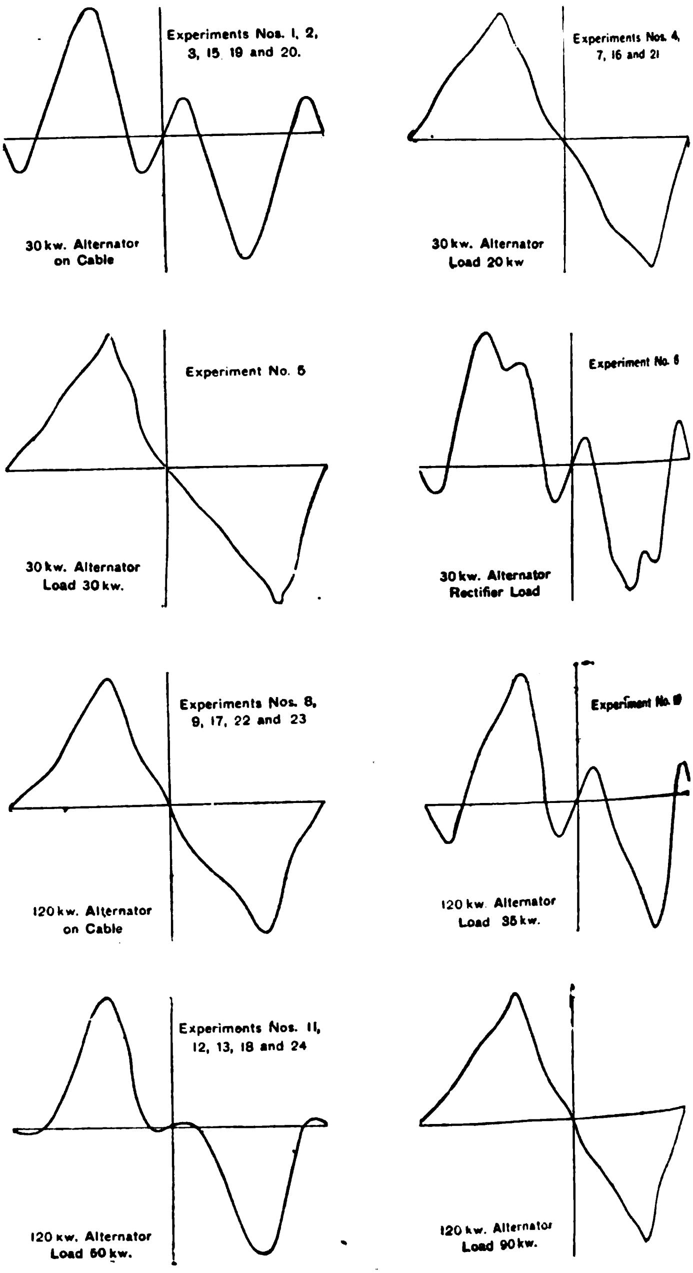
The condensers I have made have been constructed from filter paper: I have not until recently had command of the special papers which are used in making artificial cables, and which, if they will stand the treatment, I should expect to be even better. As a dielectric I know nothing better than vaseline or a mixture of vaseline and paraffin. This is more convenient than burning-oil, because it allows one to attain a temperature of 130 C. without volatilising much. No doubt, however, any good hydrocarbon oil satisfying this condition would do equally well. It is, in general, better to use two thin sheets of paper than one thick one, in order that if there is a fault anywhere in one sheet we may have the other to depend upon. The purest white filter paper has been found to do well; but the beginning and end of the matter is getting rid of air and moisture.

Mr. Minshall.

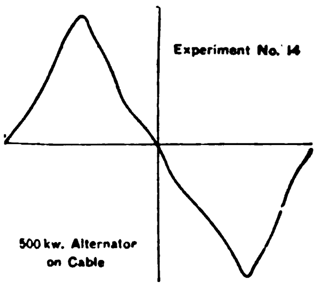
Mr. T. H. MINSHALL: The figures in the accompanying tables show the results of some experiments made at Croydon since the previous meeting. They were devoted more particularly to ascertaining three points: (1) The effect of wave form on the quantity of the capacity-current; (2) The power-factor of the cables with different wave forms; and (3) The effect on the capacity-current of a small load at the end of a cable. We started with the idea of proving that Mr. Mordey's figures were wrong and ever so much too high. The first thing I did was to take the various wave forms of three different sizes of machines under various conditions of load, and they gave the various currents shown in Table I. The machines were all by the same maker, and the various wave forms shown in Fig. K have been sketched from observations on the oscillograph. As regards the watts, the wattmeter readings probably vary slightly with different wave forms; but there can be no doubt whatever with regard to the current readings, as they were taken with Siemens dynamometers. The impossibility of calculating capacity by the usual formula is shown by the fact that on machines of the same type we got capacity-currents varying from 2·67 amperes to 1·85, which latter is the capacity-current given by the 500-kw. machine. The differences shown, confirm what was, of course, well known, and what Mr. Mordey has already mentioned—namely, that it is impossible to make a commercial test of capacity unless you have some means of making perfectly certain that you have a sine wave. As a matter of fact, it is only by using a copper-cored machine, such as a Mordey alternator, and a good cable that you can possibly get a good wave. That probably accounts for the fact of Mr. Mordey's figures agreeing

Mr. Minshall.

WAVE FORMS APPLIED TO CABLE.



Mr. Minshall.



approximately with the calculated capacity. If you have machines like those at Croydon you do not get a sine wave, as you see. The next thing we did was to measure the power-factor of the cable. It has been said by Dr. Sumpner that a cable cannot be got with a power-factor of ·1, as the author found. I do not want to say anything as to how that figure has been got by the author, but I am inclined to think that the discrepancy between the statements of Professor Ayrton and Dr. Sumpner, on the one hand, and Mr. Mordey's and my own figures on the other, is due to the fact of the variation of insulation resistance and the absorption factor of the dielectric mentioned by the last speaker not being taken into account. The cable to which these figures refer has a low insulation resistance. Mr. Mordey did not mention what his insulation resistance was; but the condensers used by Dr. Sumpner probably have an insulation resistance of many hundreds of megohms. As the dielectric hysteresis is believed to be a function of the insulation resistance, the discrepancy is not surprising. As a matter of fact, these watts measured differ according to the wave forms. The readings on this cable were taken with two Swinburne wattmeters, and also with two Thomson's inclined coil instruments. All the readings in the first table have been checked, and these four instruments agree within 3 per cent. One wattmeter has been specially checked upon low power-factors at the Central Institution, and the agreement of this instrument and the other three on inductive and non-inductive load is remarkably close. Of the four instruments, half the tests were taken with a 20,000-ohm coil in the shunt and half with a bank of lamps. We got a power-factor of 0·1, due possibly partly to the fact of our cable having an insulation resistance of only half a megohm. This is not so. I have since obtained the same results with an insulation of 50 megohms. It has been used for two years as a 2,000-volt cable. As a matter of fact, makers are making very much lower insulation resistances than formerly. The consulting engineers are trying to keep them up; but the cable-makers, of course, are trying to keep them down. Once you get them lower, you avoid a lot of trouble. With our 5,000-volt cable, by having much lower insulation resistance than before, we have avoided a lot of trouble. I see no reason to doubt any of these figures; we have checked them in every possible way by many methods. I have had the assistance of Mr. Duddell, and we have gone most carefully into the question in every

Mr. Minshall.

way. As a further check I have made the test which Dr. Fleming suggested, viz., using a motor-generator. I took particular steps to avoid changing the efficiency of the machine due to the low power-factor of load by loading up the motor generator with a large non-inductive load. Then I measured the increase in the D.C. watts taken when the cable was switched on. The increase was almost exactly the mean of the results shown in Table I. Then, with regard to the other question of running a machine, I entirely agree that capacity in cables is a very good thing indeed in power systems, and the capacity has helped us to improve the power-factor of arc lamps. I have taken the same machine running on each one of the various wave forms, and find that a very small load at the other end of the cable reduces the capacity-current taken by the cable very considerably. This is seen in the lower part of Table II. Another experiment was undertaken to show that with a certain wave form and suitable capacity and non-inductive load at the other end of the circuit, you may actually have *fewer* amperes entering in the cable than you get out at the other end. That is not a kind of perpetual motion, but merely a phase shifting—that is to say, under certain conditions by increasing the capacity in the cable reduce the current entering in.

Table III. shows another advantage due to capacity—*i.e.*, the marked decrease in exciting energy required for the machines.

Mr. Minshall.

TABLE I. (*Minshall.*)

Losses in V.B. Concentric Cable.

Length of Cable, 7,460 yards.

Section of Conductors, 0·10² Concentric.

Total Insulation Resistance, 0·5 Megohms.

No. of Experiment.	Machine running.	Input at Station end of Cable. C.	Watts.	P. F.	Watts wasted in Cable. C^2R due to Capacity Current (approx.)	Leakage Losses (approx.)	Dielc. Hysts. Losses.	
1	30 kw. Alter.	2·44	459	0·092	14	8	425	No load on end of Cable.
2	"	2·35	489	0·101	13	8	468	
3	"	2·37	505	0·103	13	8	484	
4	"	2·18	459	0·102	11	8	428	
5	"	2·03	420	0·100	10	8	402	
6	"	2·41	499	0·101	14	8	477	
7	"	2·10	431	0·100	11	8	412	
8	120 kw. Alter.	2·14	388	0·088	11	8	354	
9	"	2·07	459	0·108	10	8	441	
10	"	2·67	551	0·100	17	8	526	
11	"	2·34	367	0·076	13	8	334	
12	"	2·28	469	0·100	13	8	451	
13	"	2·29	507	0·108	13	8	486	
14	500 kw. Alter.	1·85	384	0·101	9	8	367	

Notes:—Swinburne Wattmeter (*a*) with Potentiometer consisting of lamp bank.

Swinburne Wattmeter (*b*) with 20,000 Resistance direct on 2,000 volts.

Thomson Wattmeter, No. 9,608 with Potentiometer.

Mr. Minshall.

TABLE II. (*Minshall*).

No. of Expt.	Machine Running.	Input at Station End of Cable.			Output at Far End of Cable.			Watts wasted in Cable.				
		C.	Watts.	P.F.	C.	Watts.	P.F.	Total.	C²R Useful Current.	Difference.	Leakage Losses.	
*‡15	30 kw. Alter.	3·66	5,250	0·70	2·22	4,680	1·03	570	18	552	8	Non-Inductive Load on End of Cable.
*‡16	" " "	3·52	5,180	0·72	2·26	4,660	1·01	520	19	501	8	
*‡17	120 " "	3·50	5,215	0·73	2·31	4,690	1·00	525	20	505	8	
*‡18	" " "	3·60	5,110	0·69	2·26	4,620	1·01	490	19	471	8	
*‡19	30 " "	2·48	1,870	0·37	0·89	1,365	0·75	505	3	502	8	Inductive Load on End of Cable.
†20	" " "	2·33	1,933	0·40	0·87	1,332	0·75	601	2	599	8	
*‡21	" " "	2·22	1,852	0·41	0·89	1,398	0·77	454	3	451	8	
*‡22	120 " "	2·16	1,798	0·41	0·88	1,387	0·78	411	3	408	8	
†23	" " "	2·21	1,902	0·42	0·86	1,332	0·77	570	3	567	8	
*‡24	" " "	2·36	1,798	0·37	0·89	1,365	0·75	433	3	430	8	
25	30 " "	6·78	—	—	7·50	—	—	—	208	—	8	Load on Cable.
26	" " "	9·48	—	—	10·00	—	—	—	370	—	8	
27	120 " "	8·81	—	—	9·41	—	—	—	328	—	8	

NOTES:—* Swinburne Wattmeter (*a*) with Potentiometer. † Swinburne Wattmeter (*b*) with 20,000 Resistance direct on 2,000 volts.
‡ Thomson Wattmeter No. 24,425 at far end with Potentiometer.

Mr. Minshall.

Experiment No.	Difference between current put in and useful current leaving.	Experiment No.	Difference between current put in and useful current leaving.
15	1·44	21	1·33
16	1·26	22	1·28
17	1·19	23	1·35
18	1·34	24	1·47
19	1·59	25	− 0·72
20	1·46	26	− 0·52
		27	− 0·60

TABLE III. (*Minshall.*)

Machine Running.	Voltage on Cable.	Exciting Current for Constant Voltage reduced	
		from	to
30 kw. Alternator	10,000	5·8 amperes	2·5 amperes
" " "	5,000	5·8 "	4·7 "
" " "	2,000	5·8 "	5·4 "
120 " "	10,000	17·5 "	13·2 "
" " "	5,000	17·5 "	16·0 "
" " "	2,000	17·5 "	17·3 "

Mr. Fricker.

Mr. G. C. FRICKER (*communicated*): The very animated discussion on Mr. Mordey's paper is the best testimonial to its value. Whether the results obtained by him as to the losses in the dielectric of cables are right or wrong, he has certainly established the fact that there *is* a loss well worthy of study, and has brought home that fact in a direct and practical way which practical men will appreciate. I am not in a position to contribute the results of any tests of my own on this point, and indeed the results obtained by the various experimenters which have been already brought before the Institution are sufficiently conflicting to justify considerable scepticism as to the utility of the methods or instruments employed. I would like, however, to suggest that useful information is likely to be got on the subject by making tests at various frequencies and carrying these up as high as possible.

Mr. Fricker.

From the known properties of dielectrics in delaying the discharge of a condenser, it is obvious that the power-factor must increase, and, I should imagine, increase rapidly with the frequency of the alternator.

The condenser may be considered as having a periodic time of its own, and just as a frictionless pendulum could swing in its own periodic time without the expenditure of power, but would require energy at any accelerated rate, so must work be done on the dielectric in order forcibly to discharge it synchronously with the periodic time of the alternator. I should therefore expect to find the power-factor for high frequencies go up to a figure even considerably higher than that given by Mr. Mordey, and I think that by carrying out such experiments the exact characteristic curve of the discharge could be found and data deduced which would materially assist us in the right choice of a frequency.

On the latter part of Mr. Mordey's paper I have only congratulation to offer, because I think his device, although doubtless perfectly well understood in principle beforehand, is worked out in quite a unique way, and the intentional and intelligent balancing of capacity and inductance as carried out here is a very different thing from the general sort of feeling of satisfaction a station engineer may have because he finds his transformers help to keep down "surging" in his mains, or the capacity of his mains helps to diminish his magnetising current.

Mr. Sayers.

Mr. H. M. SAYERS (*communicated*): Mr. Mordey merits the thanks of electrical engineers for bringing before the Institution some important aspects of alternate current working not hitherto adequately dealt with from a practical point of view. Whether he did or did not measure correctly the dielectric losses in the County Company's cable, his statements have stirred up a useful discussion, and brought to our notice what are virtually to the average engineer "new facts." The difficulty in accurately measuring loads of very low power-factor; the influence of wave form on capacity-current (which I suggest should be called "displacement" current—the "capacity" of a cable is so generally used as meaning current-carrying capacity, that a new word seems needed) are among these. He has also made known an engineering application on a large scale of magnetising or lagging current to neutralise a leading or displacement current. These results deserve the thanks of working engineers at least, and it is difficult to see in the paper any adequate excuse for the aggressive tone adopted towards him by some of his critics.

Choker compensation for displacement current will find practical employment in cable testing, especially in testing cables at high pressures after laying them. In illustration, I may mention that I have in use for this purpose a motor-generator set, the alternator armature of which has to carry a current of 3 amperes, at 2,000 volts alternating. It is thus a 6 K.W. machine working on a maximum load of perhaps 100 watts. This seriously impairs its portability, and made its cost relatively heavy. To test a few miles of concentric trunk main at 10,000 volts has involved the use of large alternators and transformers; and resort has been necessary to such devices as cutting down the frequency and other makeshifts. Adjustable chokers should in future largely reduce these inconveniences. Though ironless

chokers will give closest compensation, they are not readily adjustable, and probably iron circuits, with variable gaps, will be found most convenient. I have not met with any alternating distributing system in which the leading current preponderates even at lightest loads. The improvement in transformer no-load losses (in which Mr. Mordey has taken a good part), and the rapid displacement of the small "house" transformer, have tended in this direction, but evidently Mr. Mordey has found one case which may be typical. I suggest, however, that excess in this direction should be guarded against by specifying for maxima displacement currents in the cables under definite conditions of frequency and voltage—a course I have taken in several cases. The specification of wave form to be used in such tests seems hardly necessary, as any probable departure from a sinusoidal curve can only increase the displacement current. I have met with serious trouble in mains, apparently due to resonance. Repeated instances of extensive cable break-downs occurred, each case marked by many faults appearing simultaneously. On each occasion these took place during the daytime with light load. As the full load voltage was quite 10 per cent. higher than that during daylight, this seemed strange. But the full load frequency was about 90 $\sim$, whilst during the daytime it was often 70, or even lower. Direct measurement of the capacity of scores of miles of mains connected to hundreds of transformers was, of course, impossible; but calculations based on probable values showed that resonance conditions were quite probable at the lower frequency. Also voltmeter records showed a distinct upward kick just before one of the failures. I, therefore, increased the low-load frequency, and no more wholesale failures occurred. The cables in this case were mostly single rubber, not sheathed, lying in rather large pipes, and their capacity would vary materially with different conditions of wetness in the pipes. Hence the trouble was not constant. Mr. Sayers.

It will probably be found that resonance conditions are likely to be approached in practice as frequency is reduced, and the point must be considered in designing large distributing systems at high pressures.

There is one source of dielectric loss in cables under alternating pressures which has not been mentioned clearly in the discussion, but should be considered. It is due to variable specific inductive capacity in successive layers of the dielectric. Neglecting the ohmic resistance —the slope of potential across each layer is inversely proportional to its specific capacity. If this quantity and the dielectric strength are both low (as in a gas for example), sparking may occur across such a layer. Hence air spaces may increase the dielectric loss, and even where sparking does not occur some molecular disturbance of a lower order, a kind of electrolysis, perhaps, may take place. This may lead to slow deterioration of the material. The porosity of rubber, and the unfortunate experiences in some places with rubber cables, may be due to one or both of the causes above suggested. The heating in German multiphase cables, reported by Mr. Kapp, may possibly be accounted for by their construction. The three-core twisted form with fibrous packing may well have air layers between the individual cores.

When single rubber cables are used as 2,000 volt alternate-current

Mr. Sayers. leads, minute sparks pass between their exteriors when brought into light contact. For this reason the Board of Trade has required such cables to be lapped with metallic foil where passing through boxes and transformer pits, to prevent ignition of escaped gas. With 4,000 volts the sparks are both visible and audible. This air-gap sparking will cause faults in rubber cables in a comparatively short time, and when taking "inner" conductors of concentric rubber mains (the "outers" being earthed) to switch or transformer terminals, I have found it imperative to keep the rubber well away from earthed metal, or else to wrap it closely with earthed foil or strip. The close contact apparently affords sufficient paths for the current to prevent the sparking across air-gaps.

These facts show that disruptive breakdown of insulating layers of low specific capacity occurs under practical conditions even with only 2,000 volts alternating. The losses due to them are of the nature of leakage, but would not be apparent under continuous pressure tests as usually made. Such effects may account for some of the apparently large variations in cable dielectric power-factors. The behaviour of glass, mentioned by Mr. Swinburne, may be due to electrostatic heterogeneity, that substance being a mixture of divers silicates.

I would suggest that the dielectric power-factor may prove to be a valuable indicator of the probable durability of cable dielectrics for alternating pressures, and that an interesting question bearing on this and well worth investigation, is whether the power-factor varies with different pressures. If in any particular material it increases faster than the pressure, this may well be due to heterogeneity and an indicator of rapid deterioration. Our present information as to dielectric permanency under alternating pressures is confined to a very few materials suitable for cable insulation, has been purchased at a high price, and is only capable of extension by costly and lengthy experience unless some such test as that now suggested should be found to give reliable guidance.

In respect to the measurement of these very small power-factors, it would seem that an electrostatic wattmeter could be devised free from the sources of error which are inseparable from wattmeters of the dynamometer type—since every current producing a field must have some lag. Such an instrument would meet a want.

In paper cables I have found a somewhat marked discrepancy between the capacity tested by the usual ballistic method and the results of displacement currents at high voltages and frequencies. Rubber cables have shown a much closer agreement. My opportunities of comparison have, however, been few, and insufficient to serve as a basis for a general statement. The tests were made with alternators, giving nearly sine curves. The much larger displacement currents due to E.M.F. curves roughened by strong harmonics, or sharply peaked, are obviously due to the real frequency being higher than that of the fundamental in the one case, and to the maximum P.D. being higher in terms of the virtual P.D. in the other case.

This difference is favourable to alternators giving sine curves, the virtues of which seem to be rather better appreciated now than they were a few years since, when it was fashionable to belaud iron armature

alternators, despite their irregular and steeple-like E.M.F. curves, poor characteristics, and rather low efficiency. That they could be "short-circuited with impunity" appeared then to be the only virtue that counted. Mr. Sayers.

On the important question of the cost of producing the displacement current, my experience is that a generating set cannot be run at full voltage for less than about 20 per cent. of the cost of running it fully loaded. It follows that "phantom" watts are relatively expensive, whether due to lagging or leading currents. The former are worse because greater excitation is needed for a lagging than for equal leading current. Hence any practicable device for reducing the "idle current," whether leading or lagging, may have a considerable value to alternating supply systems. The condenser has been long ago suggested to cancel the lagging current, but a commercial form does not seem to arrive. The choker for the leading current may have a better chance. It is not to the point that one adds choker losses to condenser losses; if these two can be supplied by running a small unit instead of a large one, the saving in cost of running will quite outweigh the little extra energy wasted outside the alternator, and even the total energy wasted will probably be much smaller.

Even in the extreme cases cited by Mr. Mordey, the dielectric losses are not a large fraction of the total energy transmitted by the supposed cables, if their load-factor is a reasonably good one, and it is certain that good load-factors are indispensable to the commercial success of long-distance transmission undertakings under usual conditions. Where this is not the case (as in some of Professor Forbes' suggested instances) transmission losses will be of trifling importance.

An instrument, fit for a central station switchboard, which would show phase difference and its sign, at any moment, for the whole load of the station, any feeder or alternator would fill an empty place very acceptably. Professors and instrument makers have here an opportunity of added usefulness. The oscillograph is hardly the tool for such work obviously, though its power to investigate some of the problems of alternate-current work would seem to be great, and useful results should soon make themselves evident.

Mr. Stuart A. Russell (*communicated*): Mr. Mordey's paper may be divided into two parts—first, that which deals with the wattless condenser current, and the means by which this current can be provided without calling on the generator to supply it; and secondly, that which deals with the hysteresis loss in the dielectric. With regard to the first we have been told in the discussion that the paper contains nothing new or which was not known to many people ten years ago. This may be so; but those who knew do not appear to have been able to put before the men practically engaged in the generation and distribution of alternating currents a clear statement of how to provide the condenser current for their cables without supplying that same current from the generator. After the last meeting I tried to get a copy of the Physical Society paper referred to by Professor Ayrton, but was unable to do so, as it does not appear to have been published in the Proceedings of the Physical Society. I have therefore had to fall back on Mr. A. Russell.

Mr. A. Russell.

the abstract published in the technical journals, where I find a bald statement that "On joining a condenser and inductive coil in parallel, an ammeter in the main circuit indicated 5·5 amperes, whilst those in the branches showed 6·4 amperes passing through the condenser and 10 amperes through the coil." This result compares very unfavourably with that which Mr. Mordey has obtained, and does not, to my mind, suggest that the authors of the paper had any idea of the practical application to which Mr. Mordey directs our attention, or they would have given an example showing a far greater difference between the condenser current and the main current. Again, in the discussion on Dr. Fleming's paper, read in 1891 before this Institution, most of the people spoke who might be expected to know about this matter; but I find that not one of them, not even Professor Ayrton, drew attention to the fact that there was a means of providing this condenser current, amounting to about 45 amperes with 10,000 volts or 600 apparent E.H.P. without calling on the alternator to produce it. It appears to me, therefore, that Mr. Mordey's paper should be cordially welcomed, at any rate by everybody engaged practically in the distribution of high pressure alternating currents, as it directs attention, in what he calls the vulgar tongue, to the losses incurred by supplying this condenser current from the main generators, and further tells us how these losses may be reduced to a minimum.

With regard to the hysteresis loss in the dielectric, there appears to be little doubt but that Mr. Mordey has exaggerated this loss; but his paper has stirred up interest in the question to such an extent that our real knowledge on the subject is likely to be much increased by the experimental data which are now being collected by various people. These experimental data are much wanted, as the power-factor has been too much spoken of, both in the paper and discussion, as though it were a constant, and there is much to be learnt concerning the effect of variation of stress in volts per centimetre, of the imperfect homogeneity of the various dielectrics in practical use, and of the varying conditions of manufacture and of ageing of the dielectric, all of which will, I think, be found to affect the result considerably.

Mr. Esson.

Mr. W. B. Esson (*communicated*): I am not sure that I agree with Mr. Mordey as regards what he calls the "Ohm's law" of the subject, without further investigation. Certainly the readings he obtained and which he plots in Fig. 1, if they can be held to prove anything at all, prove that the current rises in a *curve* and not in a straight line, and proportionality to the pressure is not manifested, as has been assumed by the drawing of the line with a ruler. There are good reasons for believing that the current is not proportional to the pressure, and, in the absence of very complete and lengthy investigation, it would be unwise to assume about this matter an Ohm's law or anything else. The capacity of insulating materials under different stresses and under long and continuous stress is very imperfectly understood.

The action of a choking coil in supplying capacity-current has, of course, been long known, though I am not aware that it has ever been proposed before to employ it as part of an electric station equipment. Years ago the matter was fully understood, and its not being adopted

in the above sense is probably because the composition of the circuits in a general scheme of distribution is such as always to cause the currents to lag, capacity consequently becoming an actual advantage. With the longer lines of the Power Bill schemes there will of course be increased capacity; but from their nature the power circuits again are more likely to tend to a lag of current, and here capacity may prove, as before, a blessing. In power schemes with overhead lines the equivalent of capacity is sometimes purposely introduced, and I have known one at least where the capacity of the five-mile underground line proved salvation, as certainly but for this it could not have worked, *i.e.*, unless some form of phase rectifier had been added. Mr. Esson.

The thanks of the Institution are due to Mr. Mordey for having brought prominently to the attention of the members the hysteresis loss in cables, and his paper will accordingly have good results. But of Mr. Mordey's figures for these losses the less said the better. The author does not appear to be lucky as an original investigator, and it is perfectly clear that, whatever in his experiments on the County cables he was measuring, it was not power, and that the results he obtained are something like four times larger than they should be. This is important because it is the power that costs the money. The wattless or capacity-current, contrary to Mr. Mordey's views, costs nothing unless the capacity is so abnormally great as to necessitate sensibly larger engines being coupled to the generators than would otherwise be required. This is an extremely unlikely case; but, if it were so, the only extra cost would be in the extra steam required to drive the larger engines idle. Say, on account of capacity, we had to put in a 1,100 k.w. set instead of a 1,000 k.w. set. Working condensing we should use an extra 500 lbs. of steam per hour right through, costing perhaps 5d. Such a set would never be run at less than half load, so it is easy to see that the addition to the cost of the unit is quite infinitesimal.

Professor E. WILSON: Assuming a power-factor of ·124, Mr. Mordey calculates that at 6,000 volts and 50 periods per second this cable dissipates 1,206 watts per mile. With 47·2 amperes in each conductor the copper loss is also 1,206 watts per mile. The total dissipation in the $5\frac{1}{2}$ miles of this cable is therefore 13,300 watts, and this is 4·7 per cent. of the power which would be transmitted at unit power-factor, namely 283,000 watts, or it is 9·4 per cent. with a power-factor 0·5. If this dielectric loss is a fair representation of average practice, I think one might apply a differential test so as to measure it as a direct quantity. Professor Wilson.

If V and A be volts and amperes at transmitting end and $V - v$ $A - a$ be volts and amperes at receiving end, then $Av + Va - av$ is the loss in the cable at any moment, and can be split up into two classes of loss, namely, $v\left(A - \frac{a}{2}\right)$ and $a\left(V - \frac{v}{2}\right)$. If this expression be integrated over a half period and divided by the time of a half period, the result is the average watts required to be measured as a direct quantity. Two wattmeters having no mutual induction, but having their moving systems rigidly fixed together, might be employed. Each wattmeter would be working on a large power-factor, and the loss would be

Professor Wilson.

measured when the cable is loaded, and when the full self-induction of the cable is felt. The dissipation of energy in the dielectric may be the same when the cable is loaded and unloaded. This is, so far as I know, a still unsettled point in connection with alternate current transformers, in which it has been stated that the core-losses are smaller on load than on open circuit.

I have looked carefully and cannot find the thickness of rubber in this cable, or any means for calculating the specific-inductive capacity. This is an important matter, as we ought to know the volts per cm. of dielectric thickness.

I think it would greatly aid in drawing further conclusions if Mr. Mordey would also give particulars of the wave-form and the way in which the instruments were tested for accuracy.

Mr. A. Russell.

Mr. ALEXANDER RUSSELL (*communicated*): I have been very interested in studying Mr. Mordey's results. His paper has certainly given us clearer notions of the difficulties due to capacity which alternating-current engineers have to overcome. We have not yet sufficient experimental evidence to justify us in adopting any simple empirical formula for the dielectric loss. It would be very wonderful if it were simply a function of the effective voltage and independent of wave shape or area. Whatever is the real action that goes on in the dielectric, I think that we are justified in concluding with Mr. Steinmetz that it distorts the wave of P.D. This distortion may be small; but even a small distortion considerably modifies the balancing action of condenser and choking coil currents. For example, a parabola is practically indistinguishable from a sine curve—it has the same rounded shape and is only about three per cent. flatter; yet if the wave of P.D. at the terminals of the cable in Mr. Mordey's experiment (Fig. 4) were parabolic, then it would be impossible to cut down the current in the main to less than 0·65 of an ampere, even if there were zero loss in both the cable and the choking-coil. If the wave were triangular, then the minimum current would be 2·45 amperes, and if the wave form were rippled or very peaky, the balancing action of the choking-coil would be of little use.

It is important to realise the difference between the action of condensers and choking-coils on the harmonics in the applied wave. The condenser current shows the harmonics magnified, but in the choking coil-current they are to a certain extent smoothed out. The current-wave in a condenser is less like a sine curve, but in a choking coil it is more like a sine curve than the wave of P.D. at the terminals. It is this action of condensers and choking-coils that makes the sine form of wave produce in them the minimum and maximum currents respectively. It also has a bearing on the "resonance" method of testing used by Mr. Mather. In this method the same current flows in both the choking-coil and the condenser. Hence the wave of P.D. across the choking-coil terminals is more distorted than the wave across the condenser terminals. It follows also if the circuit be adjusted for resonance of the fundamental harmonic that the P.D. across the choking-coil terminals will be greater than the P.D. across the condenser terminals.

I should like to point out the limitations to the use of the ordinary

formulæ for condenser and choking-coil currents. The formula for the condenser current is Mr. A. Russell.

$$C_1 = \alpha V K f$$

where α is a constant depending on the shape of the wave. The smallest possible value that α can have is 2π, and it has this value for the sine curve. For a parabolic wave the error in taking 2π for α is 0·7 per cent., and for a triangular wave it is 10 per cent. If it is rippled or very peaky the error may be much greater.

The formula for a choking-coil is

$$C_2 = \frac{V}{\beta L f}$$

where β is a constant depending on the shape of the wave. The minimum value of β is 2π, but the error made in taking 2π for β is much smaller than in taking 2π for α. Even for a triangular wave it is less than 1 per cent. This is due, of course, to the constraining action of the choking-coil forcing the current wave to assume an approximate sine form. The graphical phase difference ϕ between C_1 and C_2 is given by the formula

$$\text{Cos}\,\phi = -\frac{\beta}{\alpha}$$

Now, for this phase difference the minimum current in the main got by varying C_2 is $C_1 \sin \phi$; for very peaky waves ϕ is nearly 90 degrees.

The values of C_1 and C_2 do not change much for a small distortion of the wave from the sine curve form, but the resultant current changes rapidly, hence a measurement of this current might be used to test how nearly the P.D. wave produced by an alternator approached the sine form.

In Mr. Mordey's experiment (Fig. 4) the condenser current vector makes an angle of 82° 53′ with the P.D. vector, and the choking-coil current vector makes an angle of 87° 39′ with the same vector. The sum of these two angles is 170° 32′, but the angle between the current vectors is only 164° 26′. Hence we must represent the three vectors by lines drawn in space. The vector representing the current in the main is always in the same plane as the other two current vectors, as a linear relation connects the instantaneous values of the three currents. Hence the minimum phase difference between the main current and the P.D. vector is the minimum angle between the P.D. vector and the plane containing the currents. Now if α, β and γ be the three angles of a solid angle, then the minimum angle θ between one of the edges and the plane opposite it, which we suppose to contain the angle γ, is determined by the equation

$$\sin\theta = \frac{\sin\omega}{\sin\gamma}$$

where $\sin\omega = 2\sqrt{\sin\sigma\sin(\sigma-\alpha)\sin(\sigma-\beta)\sin(\sigma-\gamma)}$ and σ is half the sum of the angles α, β and γ. Substituting Mr. Mordey's phase differences we find that θ is 52° 24′, and cos θ is 0·61. This is the maximum possible power-factor with the phase differences with which Mr. Mordey was working, and this is the result he obtained.

The maximum power-factor of the combined circuit being only 0.16

Mr. A. Russell.

shows that the shape of the resultant current wave is very different from the shape of the P.D. wave. A triangular and a sine curve have a maximum power-factor greater than 0·99.

I agree with Mr. Mordey's remarks about the value of condensers for increasing the power-factor of alternating current networks. I would suggest that, instead of putting the condenser straight between the mains, we put it across the secondary terminals of a step-up transformer, the primary terminals of which are put between the mains. For example, if we put a one microfarad condenser across 500-volt mains, the frequency being 50 we only get a current of about 0·2 of an ampere. If, however, we put it between the 5,000-volt terminals of a step-up transformer, we should get a current of 2 amperes in the secondary, and there would therefore be a current of 20 amperes in the primary with a large angle of lead. If n be the ratio of transformation the current is increased n^2 times. So that quite a small condenser can be used to get large balancing currents.

In Mr. Mordey's choking-coil as the current diminishes so also does the angle of lag. If we wish to vary the lagging current, keeping the angle of lag always very large, we could easily do this by putting choking-coils in parallel across the secondary terminals of a transformer the primary of which was connected between the mains.

Mr. Addenbrooke.

Mr. G. L. Addenbrooke (*communicated*): Mr. Mordey's paper is a difficult one to deal with, as it raises at least four important and specific points, each of which has not necessarily much connection with the others. As, however, I have worked over a great deal of the same ground during the last few years, I venture to submit the following remarks on points deduced from my own experiences.

The capacity-current in systems of mains is one I have always had fully in view in dealing with large power systems. Although I agree with the letter from Dr. Hoor in the *Electrician* of February 8, 1901, that the effect is capable of being dealt with, still Mr. Mordey has done good service in drawing attention to the fact that the effect may be large, and I think this is most likely to be the case in the early days of power distribution, when large systems of conductors have had to be laid down and the load is comparatively light. It appears to me that all Mr. Mordey says under this heading is a remarkable commentary on the unwisdom of the Board of Trade Regulations which practically prohibit overhead wires in this country. Although power distribution on an enormous scale has been carried out on the Continent, and in America, it has almost wholly been carried out by means of overhead wires, where the effects described by Mr. Mordey do not occur. The Board of Trade prohibits us adopting methods by which great industries have been safely and advantageously built up on the Continent and in America, and forces us to adopt expensive and untried methods, which at any rate are liable to serious inconveniences even if by skill and care they can be got over.

Coming now to the watt loss in the dielectric, I must say I was very much startled by Mr. Mordey's figures. While aware for many years that there was a loss of this character, I had no idea that its magnitude was at all comparable to the figures given for it. Since Mr. Mordey's

Mr. Addenbrooke.

paper I have been too busy to make any direct measurements on a cable itself, but the following results obtained on condensers may be interesting. The measurements were carried out entirely with electrostatic instruments such as described in the paper I read before the International Congress of Electricians at Paris in August last. Without giving a description of the details—I may say that an electrostatic system such as described is particularly suited for this work, and I think that the results can be obtained with a very small percentage of error.

Some months since Dr. A. Muirhead was good enough to place at my disposal a set of condensers for experimental purposes—in fact, for investigating amongst other points this very effect. These condensers were connected to an alternating current of 1,000 volts, and about 30 periods, and careful tests which Mr. C. W. S. Crawley was good enough afterwards to confirm with the writer, show that under these circumstances the power-factor is about ·011 to ·012. In fact, deducting a small fraction for loss in leads, about 1 per cent. of apparent watts is really true work. The experiments were made on condensers of three and six microfarads capacity respectively, which were probably equal to about seven to fourteen miles of ordinary cable. It is perfectly true that these condensers were made by Dr. Muirhead with great care in order to have the absorption small; but, on the other hand, it must be remembered that the dielectric is very much thinner than that of an ordinary cable, which probably would also be made of paper, and therefore the potential slope is very much greater than in a cable, which, whether rightly or wrongly, I have always taken as a serious factor.

Coming now to Mr. Mordey's suggestion of the use of a choking-coil across the circuit and the data he gives of a coil he has made. I may say that there has recently been completed to my specification an adjustable inductive resistance having a capacity of 170 k.w. on Mr. Mordey's rating. This inductive resistance is intended for putting a lag in the circuits of alternators under test. It has been wound for practical purposes with a number of circuits which have permitted a somewhat elaborate series of tests to be made on it. It would have been interesting to have compared its performance with that of the resistance made by Mr. Mordey, and I should therefore have been glad if Mr. Mordey had given the current which his apparatus takes with the iron circuit closed as compared with the iron circuit fully open, with a given voltage between the terminals. It is not possible to close the iron circuit of such an apparatus as well as in an ordinary transformer, and therefore it takes a larger wattless current than a transformer with overlapping plates, but how much it is difficult to say without experiment, as calculations are not of much value. In the large inductive resistance I have mentioned, the construction is such as to avoid as far as possible the effects from eddy currents Mr. Mordey speaks of, and though I think the tests show some extra loss from this cause beyond the losses which would ordinarily be allowed for in a simple transformer, yet I do not think it is nearly as large proportionately as the figures Mr. Mordey gives for it. At some later date I may be able to give further data regarding the work on this resistance.

Lastly, I would like to say a word on Mr. Mordey's wattmeter. In

Mr. Addenbrooke. the work I have done during the last five or six years on alternating current measurement and, in fact, since I first took the subject up some years before that, I have on numberless occasions been tempted to make apparatus constructed with transformers for raising the voltage, but I have always been deterred by the uncertainties I expected to be involved in. I think it quite possible that such an instrument, tested and calibrated by instruments which can be relied on, may be useful for approximate measurements through a moderate range and comparatively high power-factors, but I have felt that to go beyond this required great caution. Some experiments I made some months since, using electrostatic instruments, confirm the view Mr. Duddell has recently expressed in the technical press, that there was a certain amount of lag produced by magnetic leakage which at any considerable power-factor would entirely upset readings.

In the course of the debate on Mr. Mordey's paper, Dr. Fleming advocated making tests with a motor transformer and accumulators. As a matter of fact, my own tests were made up in this way, except that instead of accumulators I used the Westminster Co.'s current, the voltage being kept steady by passing the current through a variable resistance and observing a voltmeter. Owing to the leading current produced by the condenser, the reactions in the generator are considerably altered when the condensers are put on, and it is necessary to observe carefully that the speed is similar when any comparative measurements are made.

Mr. Boot. Mr. H. L. P. Boot (*communicated*): In the first place, the author is to be congratulated on presenting to a technical body a paper which is a masterpiece of simplicity, and in endeavouring to explain the subject in (as he terms it) "the vulgar tongue" so satisfactorily. Capacity measurements are taken by some of the station engineers to my knowledge, and no doubt if the results obtained, were anything like the magnitude of the loss the author has obtained they would be taken more frequently; but experience has shown that, in practical everyday working, these losses are negligible, because on nearly all alternating systems, owing to the number of transformers in use, there is bound to be a lagging current, which will more than counterbalance the capacity current. I should very much like to see the results showing the variation of capacity after the life of the cable, and whether the ordinary fibrous or paper insulated cable decreases in capacity, as one would expect it to, as it becomes drier.

On page 377 I cannot help thinking that the author takes rather an "alarmist's" view of the losses due to capacity, as I have been unable to confirm any losses of such a serious amount in concentric cables when insulated with paper, and I fancy a great deal of the loss must have been due to the dielectric employed on this particular cable. If the author would kindly inform us whether the cable he conducted the test on has been in active use? At what pressure? For how long, and in what condition the cable was afterwards, so far as insulation and withstanding the pressure test? I certainly have noticed when switching long feeders on that an engine, especially if it be a small unit, has been checked, but this, I think, has been due to the

work done in charging the cable, which, of course, is more or less a momentary loss, unless for some reason or other the cable becomes discharged by leakage and a continuous charging is taking place. However, if time permits this summer, I intend to make a careful test on a feeder three miles long for at least a period of three hours, measuring carefully the steam consumption of the engine running light, without the cable being switched on, and afterwards the steam consumption of the engine with the cable switched on; in other words, the engine having only to maintain the pressure. It is then clear that the difference in steam consumption will show the actual amount of work done, which I expect to be very little. Mr. Boot.

For some time I have been endeavouring to get at the true cost of apparent watts, so far as the actual coal consumption is concerned, or the work done by the engine, and I agree with the author in thinking that it is not much *less* than one-fourth. In practical working one would not, of course, keep a feeder charged without being connected to a transformer, and doing work of some sort, and therefore the conditions under which the author made his test are not applicable to practical working, although extremely interesting and instructive.

Some five years ago, when the Tunbridge Wells works had only been running a year, and the total amount of cables laid would not exceed ten miles, the apparent watts, *i.e.*, amperes multiplied by the volts, were considerably in excess of the true watts registered by the watt-hour meter, whereas now we find, although using the same instruments as previously, that the true watts now equal the apparent watts, *i.e.*, the reading of the watt-hour meter is nearly the same as the reading obtained when multiplying the amperes by the volts (multiplied by the time). It is possible this may be accounted for by having now some forty miles of concentric cables laid (both high and low pressure), which should have a large capacity effect and assist the lagging current, so as to bring the power-factor as near unity as possible. There is no doubt that a certain amount of work is done when keeping a cable charged, as one can usually tell whether a cable is alive or dead by grasping it tightly over the insulation, when, if alive, a distinct vibration will be felt.

Mr. G. H. NISBETT (*communicated*): Mr. Mordey has rendered a considerable service to the Institution in bringing the subject-matter of his paper to the attention of the members. It covers ground that undoubtedly has been very neglected in the past, and, whether Mr. Mordey's figures are right or wrong, the paper will have done good in inducing other people to make experiments on the lines of his. Mr. Nisbett.

The first part of Mr. Mordey's paper appears to be somewhat elementary, and I think he hardly gives central station engineers credit for the knowledge that is in them.

The feature of the paper is the reference to the losses due to dielectric hysteresis, or the power-factor of the capacity-current of a cable. The losses shown are so considerable, and so much in excess of those that it has hitherto been assumed are taking place, that a considerable flutter in the alternating dovecotes has occurred.

To show how serious a matter it is one need only instance the case

Mr. Nisbett. of the Deptford Station, where (if Mr. Mordey's statements are correct) 530,000 units per annum are wasted in dielectric hysteresis losses; and Mr. Mordey apparently wishes us to believe that the station engineers have never missed this energy! Luckily for Deptford and other extra high tension stations, there appears to be no reasonable doubt but that Mr. Mordey's figures are very seriously in error.

In the first place, I think it will be generally agreed that Mr. Mordey's use of a Thomson integrating wattmeter for the measurement of energy having so low a power-factor was a mistake. When such a meter is used to read capacity-current or nearly wattless voltamperes, if there is the slightest self-induction in the shunt coil the whole of the readings will be completely upset. (The use of a transformer in the shunt would make things infinitely worse.) One can see this when it is considered that, assuming a 2½ per cent. power-factor, the angle of the current we wish to measure is 88¼ degrees from the volts, an absolutely wattless current being of course 90 degrees. To show how difficult it is to measure currents of such low power-factors by ordinary methods, I may say that after the reading of Mr. Mordey's paper I made several experiments with a view to determining the power-factor of a cable. In the first place, by the three voltmeter method. This was a complete failure, probably owing to the fact that the errors in the voltmeters are squared, the results showing a small negative power-factor, *i.e.*, that the cable was giving energy to the circuit. In the second case I took a Thomson watt-hour meter of the type used by Mr. Mordey, but without a transformer, and put on to it a non-inductive load of about one ampere. The speed of the meter was then measured and then a capacity current of one ampere added to the circuit. There was no observable difference in the speed of the meter, thus showing a zero power-factor. The third method was with a Weston wattmeter, the shunt being connected across a known proportion of a non-inductive resistance. This method showed a power-factor on paper cable of ·0125, or about half what I believe to be the true result, the error no doubt being due to the self-induction of the fine wire coil.

I have had the pleasure of witnessing tests carried out at the works of the British Insulated Wire Company by Professor Ayrton, and referred to in Mr. Mather's remarks. The results attained by the three methods used checked so exactly with each other and with others made by different sets of instruments, that I am convinced the power-factor of ·024 for paper cable given by Mr. Mather is the correct one. This is confirmed by figures given by Dr. Hoòr in the *Electrician*, in which he gives for the Buda Pesth paper cables at 2,000 volts a power-factor of ·025.

The alarming figures shown in Mr. Mordey's tables are based not only on too high a power-factor but on too high a capacity, for the cable tested by him was a rubber insulated one, whereas this type of cable is comparatively seldom used for high tension work. By far the commoner type is paper insulated cable, and this has a capacity of about 0·4 that of indiarubber, and a special dry core high voltage cable made by the British Insulated Wire Company has a capacity of

only one-third of that of indiarubber. Therefore, to arrive at an approximation of the energy loss of cables as commonly used we must divide the figures given by Mr. Mordey by about 15. Mr. Nisbett.

To show what the loss due to dielectric hysteresis will amount to in practice, I have worked out two concrete cases.

In the first case, that of the Midland Power Company, who are laying down a system of 7,500 volt two-phase cables over a very extensive area, some of the feeders being eight miles in length. The total apparent power in the charging current of the cable will be 290 k.w., and the true energy loss in the cables 7·25 k.w. The station will have immediately 5,000 k.w. of plant, and assuming a 12½ per cent. load-factor the loss in dielectric hysteresis will be 1·2 per cent. of the units sold. When the mains become loaded to their full capacity the loss will then be only 0·4 per cent. of the units sold.

In the second case I have taken as an example a large town now working with a monophase system at 2,000 volts, and supplying over 100,000 lamps. The total capacity of the high tension network is 10 microfarads. The dielectric hysteresis loss is 520 watts, or 4,500 units per annum, and, the output of the station being 2,000,000 units per annum, the energy loss by dielectric hysteresis amounts only to something less than one-quarter per cent. of the energy sold. I think these figures go to show that the losses due to this cause are really insignificant.

Mr. Mordey suggests that dielectric hysteresis differs from magnetic hysteresis in showing no saturation effect, while Dr. Hoor holds that the power-factor diminishes with increased pressure. I am inclined to think from observed facts that the contrary is the case, and that power-factor increases with increased pressure. I am led to this opinion by some experiments made on a short length of cable built for a working pressure of 10,000 volts, and tested to 90,000 volts 100 frequency. After the application of this pressure for half an hour, although the cable showed no signs of breakdown, it was distinctly hot to the hand. This heating could not be due to conductance of current through the dielectric, as of course the insulation resistance of so short a length would be many thousands of megohms, but could only be due to dielectric hysteresis of a very much higher order relative to the capacity-current than even Mr. Mordey's figures show.

With regard to Mr. Mordey's suggestion of counteracting capacity current in cables by putting a coil with self-induction in parallel, I think Mr. Mordey certainly deserves the credit in this matter of having proposed to apply known principles to practical purposes in a systematic way, although of course the principle underlying his suggestion has been well known for many years.

I remember in the very early days of the City Company that we got into trouble by using single cables for alternating currents, and we seriously discussed the feasibility of putting condensers on the mains to neutralise the self-induction, but on calculating it out we found it cheaper to use triple concentric cables. This, of course, is exactly the converse of Mr. Mordey's suggestion. It is to be remembered that the capacity-currents of central station cables are more or less neutralised

Mr. Nisbett. by the transformers connected to them, and it is rare to find a station working at 2,000 volts in which the wattless current due to the cables exceeds one or two amperes. Certainly not a noticeable amount even at the lightest loads.

With regard to extra high tension stations, the annulment of the capacity may be of use, although its application presents difficulties. In the first place, it must be remembered that the use of the self-induction coil will add to and not diminish the total energy losses of the station, and that it is only of use at all on very light loads, for as soon as the real working load comes on to the station the capacity current practically disappears. This, of course, is due to the condensers and wattful currents being in quadrature; the condenser current is represented by the square root of the difference of the squares of the current at the source and end of the cable. This means that, if the capacity-current in the cables at a certain station is 6 amperes, then with 10 amperes of real work on the circuit the total current is represented by 11·7 amperes. With 50 amperes real work on the station the total current is 50·6 amperes, and with 100 amperes of real work 100·2, so that in this last case only ·2 amperes would remain for Mr. Mordey to neutralise, and the energy loss in his choker would probably amount to more than this.

It is therefore evident that if the device is to be of real service at the station it must only be used on very light loads, and must be switched off as soon as the work becomes appreciable.

Unfortunately, Mr. Mordey's device will not prevent undue momentary rises of pressure in high tension cable systems having capacity due to any disruptive discharge that may occur, as owing to the enormous frequency of such discharges the coil would be practically infinitely resistant as a path for current.

The device will probably prove of considerable advantage to cable makers in testing batches of cable with high pressure alternating current, as a suitable adjustable choker will enable the total current given by the alternator to be considerably reduced, and so allow the use of smaller alternators than would otherwise be possible.

I should like to know where the demand for condensers Mr. Mordey speaks about is to be found, as it can readily be met. A good condenser in the form of a cable having small conductors of large surface, and with a dielectric having a high specific capacity, can be built for a working pressure of 2,000 volts, at about £30 per microfarad.

Mr. Cruise. Mr. E. G. CRUISE (*communicated*): The salient points of Mr. Mordey's most interesting paper were, at least as I understood them, that first, electrical transmission of large powers at high voltages over long lengths of underground insulated cables was going to be at least enormously handicapped if not defeated altogether, due to the capacity losses in these insulated cables; and second, that it was very desirable for electrical engineers seriously to consider the question of how the problems involved are to be dealt with. All this in view of the recent legislation and passing of the Electric Power Bills of 1900 and our entry in this country on a comparatively unexplored and untried

electrical engineering venture. Except from Mr. Mordey himself, we failed to hear any definite suggestion as a remedy for the evils in question. Mr. Cruise.

If I presume to join in the discussion it will be to try and analyse at least one of the practical points raised by Mr. Mordey, *i.e.*, the extent of the losses. I would first like to ask Mr. Mordey a question, and it seems an important one. What was the length of cable referred to in Table I., and what was its ampere carrying power? It had a capacity of one microfarad, and the watts lost due to capacity under different voltages are given.

In the Electric Power Acts now about to be carried out, the question of k.w. transmitted in a cable, compared with the accompanying capacity losses per mile, seems to be one of cardinal importance where long distances and large powers are to be dealt with, and I want to try and show from some figures that one microfarad capacity apparently goes a long way in a high tension power transmission cable. We may arrive at the end in view from perhaps the following consideration. First of all assume that the capacity power-factor, ·124, found by Mr. Mordey is neither too high nor too low, and take it as a basis. If it can be proved to be excessive, so much the better for the arguments. Judging from the discussion at the Institution, it is not likely to be proved insufficient. Now, Mr. Mordey calculates in his paper that, with 40 miles of "go and return" concentric cable of ·5 M.F. capacity per mile running at 50 periods and 20,000 volts, the annual capacity loss would be about 2,700,000 Board of Trade units.

Assume that the cable contemplated was a 37/16 and that ·5 m.f. per mile for this size is practical. Such a cable could easily take 2,500 k.w., ten miles at 20,000 volts. Suppose in some power scheme that there were four such transmissions in various directions feeding different centres, and thus making up the 40 miles of cable.

If 5 per cent. is allowed for other losses in the cables, apart from capacity losses, it is practical to suppose that this network of cables would be dealing with some 10,500 k.w. at their outgoing ends. Now, it was satisfactorily demonstrated during the parliamentary proceedings of the Power Bills, that in a comprehensive electric power supply, a load factor of 25 to 30 per cent. was to be reasonably expected, if it did not exceed these figures. Take 10,500 k.w. on, say, a 30 per cent. load factor and we get

Board of Trade units per annum	=	27,405,000
Board of Trade units lost in capacity effects ditto	=	2,700,000
Total		30,105,000

Thus the ratio

$$\frac{\text{Units generated per annum}}{\text{Units lost in capacity effects}} = \frac{30{\cdot}1}{2{\cdot}7} = 11 \text{ (approx).}$$

From this results that the units lost in capacity taken over a year would be some 9 per cent. of the total units generated for the supply. This figure of 9 per cent. might be further reduced by reducing the periodicity, say, to 40, the capacity to ·4 M.F. per mile or less, and so on.

ise On the other hand, it would be increased by diminishing the load-factor. Of course it must be admitted that this 9 per cent. added to the other transmission losses, makes the total loss in the H.T. mains, even with a load-factor of 30 per cent., rather formidable, though I can scarcely think it would necessarily quite spoil a dividend on the capital expenditure. That could be easily gone into, though I do not propose to do so here. But it must also be remembered that this 9 per cent. is arrived at assuming generally unfavourable conditions; for example, no compensation for capacity-currents through induction, the periodicity and voltage unnecessarily high for the conditions named, and so forth.

Mr. Mordey shows that dielectric hysteresis is the only important one of the capacity losses in the mains for large cables. He also says this loss is not preventible and cannot be counterbalanced like the capacity-current itself, but that this hysteresis may be lessened.

In this connection I would submit two points; first, that if it is really of the nature of a mechanical strain in the dielectric that strain will be diminished when the charging currents and charges helping to produce it are compensated, even though the periodicity remain the same; and second, that in the H.T. cables likely to be used in the power schemes the dielectric will be thick and so, as in Mr. Mordey's opinion, the strains will be lessened.

I mention these two points, though one of them is but a conjecture, by way of emphasising the fact that when Mr. Mordey's factor ·124 is taken, as is done here, in any calculations, we must be well on the safe side. But, as already stated, 9 per cent. annual loss in capacity alone, while not quite a desperate one, is a very undesirable one, and all means of diminishing it should be investigated by electrical engineers. That capacity, on the other hand, under certain conditions produces most favourable effects, where it is present as a set-off against self-induction, is undoubted, and for any given cases the figures can be calculated.

Mr. Mordey proposes to vary the self-induction and balance with chokers. Some continental engineers have contemplated varying the capacity, always an increase of course for a given cable, but so far this latter course has not had practical success.

In Mr. Mordey's method the difficulty would seem to be to have practical means of controlling these chokers if they are placed along the cables themselves instead of at the generators. For the choker current at the plant full load and light load would have to be very different, and, in fact, the range of "apparent watts" in the chokers, over comparatively small changes of plant load, would be probably enormous. I would like to have Mr. Mordey's opinion on this point, because, while it scarcely applies to Mr. Mordey's case, in dealing with this subject in Germany recently, it has been urged that the suitable distribution of the chokers along the transmission cables is the best arrangement rather than having them all at the generating source. For in the latter case the alternators alone may be protected from the economical disadvantages of large wattless currents at light loads, while in the former case the mains themselves may also have their otherwise present charging currents compensated in part or

entirely, and so, as I take it, the cable heating and hysteresis losses probably sensibly diminished. Mr. Cruise.

I wish to add a few words about capacity effects in 3-phase 3-core cables, as I have been going into the subject recently in connection with one of the Electric Power Acts. On first sight it might seem a complicated subject, but on investigation I think it proves not to be so. At least, I refer to the same nature of effects and losses dealt with in the paper under discussion. Mr. Mordey says he has not in this paper compared the question of capacity of 3-phase cables.

It seems to me that as these are the very form of cables likely to be largely used, for other economic reasons, in the power schemes, that the consideration of them in brief is an interesting subject, and, as I hope to show, has a direct and important bearing on the present paper and discussion.

I have been able to get some figures together which may be of use to the members, and would like to have Mr. Mordey's opinion on them. The important point is that, if they are correct, the capacity losses are going to be notably less in three-phase, three-core cables than the losses found by Mr. Mordey in single-phase concentric cables. I am entirely indebted to Monsieur C. H. Guye, an eminent continental electrical expert, for many of the statistics given in working out these calculations, and he has kindly given me his permission to make use of them here. Some of the actual measures of capacity have already appeared in the continental technical papers, but I have extended them and reduced them to British units.

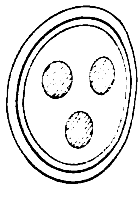
In the adjoined table there are two different examples taken, one for 10,000 volts and one for 20,000 volts. These are shown respectively as I. and II. The cables are lead-covered and armoured. They have been recently constructed by a large continental cable firm.

Mr. Cruise.

CAPACITY EFFECTS.

Three-phase, three-core cables. "Star"-connected. Neutral points to Earth.

		Case I.	Case II.
		Insulation :— Conductor to Sheath = ·36" Between Conductors = ·42"	Insulation :— Conductor to Sheath = ·72" Between Conductors = ·72"
(1)	Carrying power with 5 to 7 % C^2R loss, ·8 power-factor..........................	2,500 K.W. 8 miles	2,000 K.W. 15 miles
(2)	Voltage between conductors = V	10,000	20,000
(3)	Section of each conductor...	·21 □"	·076 □"
(4)	Capacity in M.F. per mile, one conductor to two others and sheath = k' ...	·265	·152
(5)	Ditto, three conductors to sheath = k''	·5	·326
(6)	Resultant M.F. per mile for each conductor = $K = \frac{9k' - k''}{6}$	·314	·173
(7)	Charging current per conductor-mile = $C = \frac{2\pi n K V'}{1{,}000{,}000}$ $n = 40$ $V' = \frac{V}{\sqrt{3}}$	A ·45	A ·5
(8)	Apparent loss per mile for three conductors V' $= 3\left(\frac{C \times V}{1{,}000 \times \sqrt{3}}\right)$	8 K.W.	17 K.W.
(9)	Total apparent loss for entire cable and % to full load	64 K.W. 2·6 %	255 K.W. 12·7 %
(10)	True loss if capacity power-factor = ·124	0·32 %	1·6 %



The important dimensions in the cables for Cases I. and II. are given. The cables are of the form :—

Taking the details given in order—

(1) I am not sure of the exact distances over which the cables operate, but the carrying power and distances are given as understood by the size of conductors, voltage and power transmitted on the three-phase system, star-connected generators. These

sizes and distances are of special application to the Electric Power Acts, where no distance is likely to be greater than, or even to attain, fifteen miles. Mr. Cruise.

(2) 10,000 and 20,000 volts between conductors in the above system of transmission involves each conductor in a pressure of $\frac{10,000}{\sqrt{3}}$ and $\frac{20,000}{\sqrt{3}}$ volts respectively, above earth. It is this latter voltage that influences the charging currents.

(4) One might easily expect that the practical measurement k' was the capacity to be considered per conductor. On the other hand, it is obvious that the capacity phenomena in such a cable and system are complex, and here again it is that M. Guye has made such valuable researches, both practical and mathematical, and arrived at definite and simple results.

(5) M. Guye finds that k'' must be taken into account, namely, the capacity of the three conductors in parallel to the sheath. In the measurement under (4) the two conductors and the sheath were taken in parallel and measured to the remaining conductor. k' and k'' are measurements readily taken, and M. Guye has proved that

(6) The resultant capacity $K = \frac{9k'-k''}{6}$. K, it will be noticed, is less than k'' and greater than k'; it approaches most to k'.

(7) Here I have worked out the charging current per mile of each conductor. The periodicity has been taken at 40, as the likely figure for power transmission in this country.

(8) Thence is calculated the apparent k.w. loss per mile for the three conductors.

(9) This gives the total apparent k.w. loss over the respective lengths of cable under consideration.

It is clear that the real watts cannot be more than the apparent watts, but even if they were equal they would prove tolerably negligible in the 10,000 volt cable, which voltage, I think, is likely to be far more employed in this country and in the Power Acts than 20,000 volts.

(10) But if I take Mr. Mordey's factor ·124, although I do not know how far it is right to apply it to these cables, the real watts would be very small in both cases compared to the power transmitted.

Of course it must be remembered that the capacity loss is continuous, while the kilowatts transmitted have to be considered on a 25 or 30 per cent. load factor for a large power scheme.

Taking Case II. of the cables, *i.e.*, that for 20,000 volts, which is altogether the least favourable, there is

17 k.w. apparent loss per mile,
Say real loss $= 17 \times \cdot 124 = 2\cdot 1$ k.w.

Take forty miles of transmission divided up into different circuits, and used in connection with, say, 7,000 k.w. of plant, and allowing 5 per cent. transmission losses other than capacity losses. Allow 30 per cent. load factor. We get

Mr. Cruise.

B. of T. units per annum	=	18,270,000
B. of T. units lost in capacity per annum	=	730,000
Total		19,000,000

Thus the ratio

$$\frac{\text{Units generated per annum}}{\text{Units lost in capacity effects}} = \frac{190}{7{\cdot}3} = 26$$

From this results that the units lost in capacity taken over a year would be some 3·8 per cent. of the total units generated for supply.

The worst possible conditions have been taken, and yet the loss comes out far less than with single-phase concentric cables, and is, generally speaking, well within economic bounds. It is equally certain that it would be far better to have this loss still less. That might easily be attained by keeping to the figure 10,000 volts as the working pressure, when the capacity loss would at once cease to reach a dangerous figure, in fact, it would be comparatively negligible.

I might add that the dielectric in the cables in Cases I. and II. was paper and fibre. But taking, as has been done, the capacity power-factor at Mr. Mordey's figure for rubber cables, it is all in favour of an excess estimate for losses in these three-phase cables. I would like to have Mr. Mordey's opinion on these figures and results, as, if correct, I think they have an important bearing on the question under discussion. There is, however, one important point to note. If the Board of Trade will only allow small loads, say 1,000 k.w. per cable, then the per cent. capacity losses will go up at an alarming rate, and they would eventually become very formidable.

For low power cables, say 500 k.w. and under, or somewhat higher powers for very long distances, the losses would become disastrous. In one case I have, calculated, where 10,000 volts was used to take 800 k.w. thirty miles on the three-phase system, if this transmission had been effected with underground three-core cables the capacity loss (·124 power-factor) taken over a year might easily attain 20 per cent. of the units generated. To this would also have to be added the other transmission losses (5 to 7 per cent.), making the whole transmission loss a hopelessly impracticable one.

Finally, I might remark that the continental engineers I have met with seem to fear resonance effects due to capacity and attendant insulation breakdowns, unless certain precautions are taken, far more than the capacity losses themselves. It is true that on the Continent experience has largely been with overhead transmissions; but it is nevertheless a fact that the first extensive high-tension transmissions through cables are also being done on the Continent, and therefore their experience is valuable. Apparently the figures shown here would tend to confirm one in the belief that capacity losses in well-designed power schemes will not be dangerous after all.

Mr. Baillie.

Mr. G. H. Baillie (*communicated*): It is a curious fact that among all the power-factors given by different speakers, the professorial are uniformly lower than the engineering ones. It may, perhaps, help forward the end preached by Mr. Swinburne, when the Professor and the Engineer will lie down together, if I mention some experimental

Mr Baillie.

results obtained by a professor who in this respect is among the engineers. The experiments were carried out by Professor Lombardi, and I myself took some part in them at their commencement; they are published partly in *L'Elettricista*, 1896, and later in pamphlet form, but have not yet, as far as I know, been translated into English. The power-factor found for waxed paper was 0·011, confirming other results already mentioned; for two Swinburne condensers, 0·014 and 0·023; for two samples of small cables insulated with guttapercha, 0·037 and 0·068; for two samples of glass, 0·070 and 0·132, confirming Mr. Swinburne's previous results. The power-factor of 0·068 for guttapercha cable is certainly high enough to justify Mr. Mordey's contention that the loss of energy in cable dielectrics is worthy of attention, whether the cause of the loss be called hysteresis, leakage, or imperfect polarisation.

That some part of the energy loss is due to hysteresis, that is, to a time-lag between the stress and its strain, is conclusively shown by Arnò's results; but it is probable that some is due to C^2R losses, where R includes, not merely the arbitrary resistance as measured by continuous current, but also, to use Maxwell's analogy, the resistances between the elementary condensers of which an imperfect dielectric is composed. This view is strengthened by the results of Lombardi's experiments, which show that a large energy loss is accompanied by a correspondingly slow polarisation, for in the imperfect dielectric as imagined by Maxwell the interposed resistances would have the effect of making the polarisation slow. The waxed paper condenser, which had the small power-factor of 0·011, took up 97 per cent. of its maximum charge in the shortest time given by a Helmholz pendulum—something less than 0·001 sec. The guttapercha cable, with power-factor of 0·037, took up 90 per cent. of its charge in the same time; while glass, with the high power-factor of 0·137, took up only 5 per cent. of its maximum charge. Lombardi's measurements were not made with a view of establishing any relation between energy loss and rapidity of polarisation, and are not sufficiently numerous to do so; but if the connection they indicate be confirmed, I would suggest that the curves obtained in making the insulation test of a cable might afford a good indication, if not a measure, of the energy loss to be expected. The cable-makers have every facility for taking the curves, and these may well give a better idea of the energy loss than a wattmeter, which, according to the discussion, has an average error of 1,000 per cent.

In criticising Mr. Mordey's measurement of the power taken by the cable, it was generally assumed that his readings were too high because he had used a wattmeter; as a matter of fact, the difficulty is to make a wattmeter read high enough under the conditions of the test. Self-induction in the pressure coil of the wattmeter would tend to make its readings too low, unless, as Dr. Sumpner suggested, there was sufficient to make the wattmeter read more negative watts than there were positive. This, though theoretically possible, is out of the question in Mr. Mordey's case; supposing the true power-factor to be 0·025, in order to measure a negative power-factor of 0·124, the wattmeter must have the resistance in the shunt circuit only 3,500 times its self-induction

Mr. Baillie. coefficient; as this is of the order 0·001–0·01 henry, the resistance must be only 3–35 ohms, and I do not think such a wattmeter is on the market. As an alternative way of measuring negative watts in mistake for positive, Dr. Sumpner suggests transforming down the volts. This is more feasible, if the secondary volts lag more than 180° behind the primary. Mr. Duddell, however, in the *Electrician* of February 8th, says he has measured a lag of less than 180°. It is possible that the short-circuited secondary coil may prove a source of error, due to the series coil inducing currents in it, if the two are not exactly perpendicular.

The wattless power received but little attention in the discussion, probably because it is unimportant at the pressures common in England; at extra high pressures, however, it can assume startling proportions, even in aerial lines, where Mr. Mordey treated it as negligible. This may be seen in the case of the Standard Electric Company's 3-phase line, transmitting 150 miles to San Francisco at 60,000 volts, where the engineers expect a charging current of 32 amperes, representing some 3,300 wattless kilowatts. If cables were substituted for the overhead line, the charging current would be about 20 times the full-load current.

Mr. Whalley. Mr. A. WHALLEY: Mr. Mordey's paper has a special interest to me personally, as I believe his attention was first drawn to the importance of capacity-current in connection with a large network of 2,000 volts concentric rubber cables installed at St. Petersburg by the Helsby Company, for the design and laying of which I was responsible. There are now about 250 kilometres of cable laid, having a total capacity of about 88 M.F., the capacity current being theoretically 47 amperes. It has, however, been recognised since the question was raised that instead of this current being a disadvantage, it is of service in partly neutralising the wattless current of the transformers. So large is the latter, however, that the capacity-current would have to be five times larger than at present to neutralise it. I am of opinion that in another direction the so-called high capacity is of value, as there has been an entire absence of breakdown of the cables on the present network, while preceding cables of much lower capacity gave considerable trouble; the breakdowns—as is generally the case—occurring at times of light load.

From tests made on Helsby Rubber Cables—using, through the kindness of Professor Ayrton, the same instruments which were recently used elsewhere—it is found that the losses in the dielectric indicate a power-factor well under 3 per cent. With the same cable the results vary with the alternator used, and may be reduced by using transformers. A power-factor of ·0255 was obtained off an alternator at 103 $\sim$, with choking coil and cable in parallel; while using another alternator at 50 $\sim$, without a choking coil, a power-factor of ·0238 was obtained, and of ·0228 when transformers were used between the alternator and cable.

It is of interest to note that the condition for a choking coil to balance a given capacity is that of resonance. Fig. M (K.032) shows capacity current and P.D., for a cable of ·388 M.F., fed by a particular alternator direct, when the condition of resonance is being

Mr. Whalley.

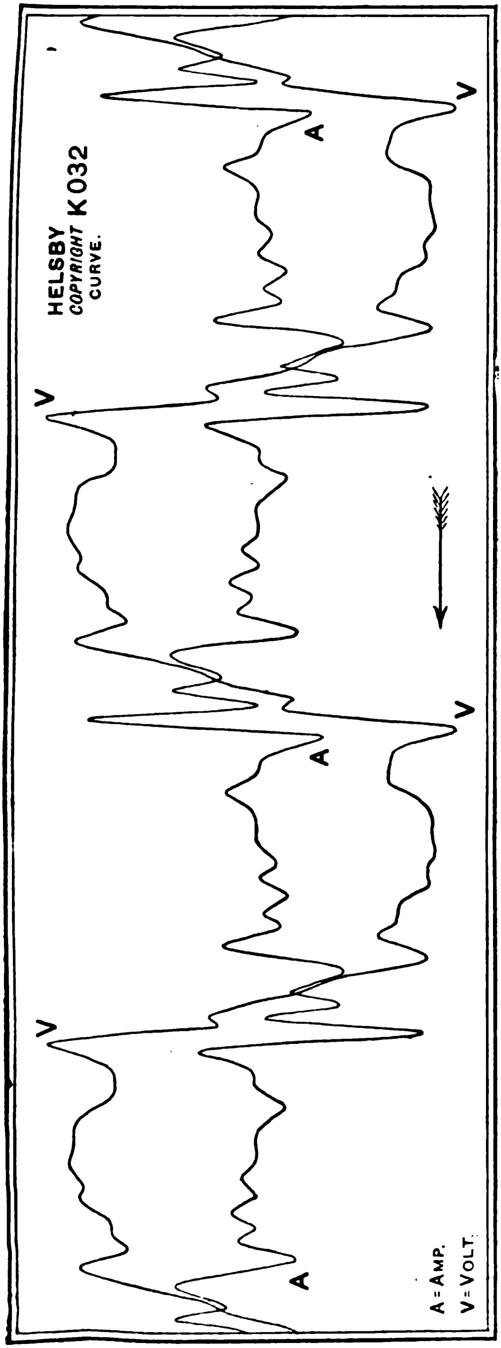


FIG. M.

Mr. Whalley.

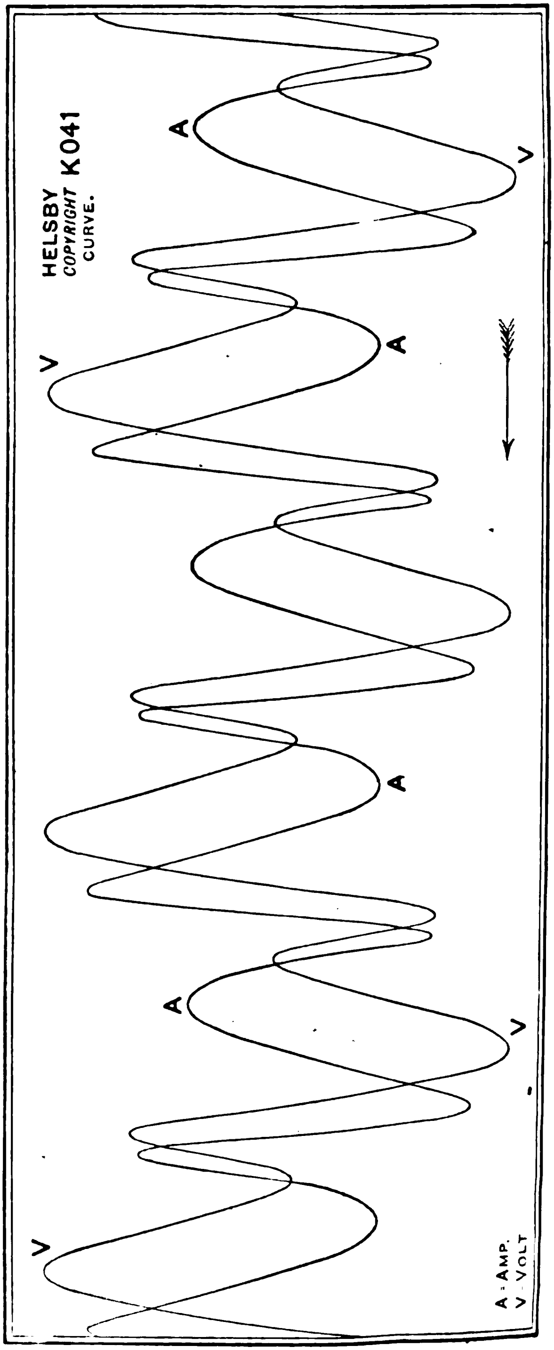


Fig. 8.

Mr. Whalley.

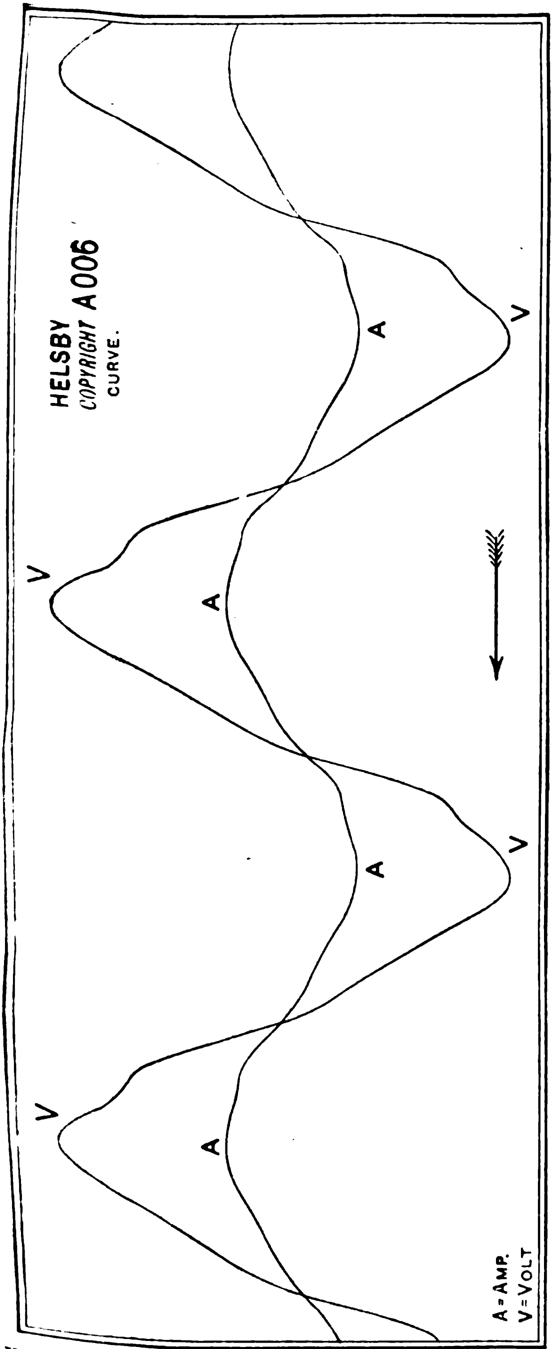


FIG. P.

Mr. Whalley.

approached. The P.D. is 2,000 R.M.S. volts, and the current 0·2 R.M.S. amperes. Some caution may be needed before using a network in a condition of resonance until it is known if there is then any special risk of the breakdown of insulation.

Fig. N (K.041) shows the capacity current and P.D., with the same alternator working on a cable of 4·90 M.F. at 1,980 R.M.S. volts, the capacity current being 6·04 R.M.S. amperes. These photographic records, and the power-factors quoted, show that the peculiarities of the alternator to be used under a capacity-load ought to be known when considering the adoption of choking coils or the value of the power-factor of a dielectric.

The same machine under a transformer load gives the curves of P.D., and current shown in Fig. P (A.006), at 2,040 R.M.S. volts, and 29·5 R.M.S. amperes, when the machine is connected direct to the transformers to avoid capacity in the primary circuit, and the secondary load of the transformers is practically non-inductive.

Mr. Spark's comparison of the capacity of paper *versus* rubber cables has apparently been made on the assumption that the paper cable would have about twice the thickness of insulation of the rubber cable tested by Mr. Mordey. For the same thickness of insulation the ratio of the two capacities is generally taken as being 2 to 3, but it would be wrong to assume from this that every paper cable has a less capacity than rubber, as a very small percentage of moisture left in the oil or paper, or absorbed after manufacture, considerably increases the capacity.

The heating of the German three-phase cables on light loads, mentioned by Mr. Mordey on the authority of Mr. Kapp, requires further elucidation from a cable-maker's point of view. Such heating, when obtained in factory tests, is generally explained by a local fault or extremely low insulation throughout.

Mr. O'Gorman raises some very interesting points, and his curves would be of great value if they were the result of actual tests; in fact, they are described as though this were the case. I believe that they are simply calculations, however, and that at the present moment the deductions drawn from them are theoretical and have still to be proved in practice.

Mr. Andrews.

Mr. L. ANDREWS: In spite of the evidence given by the majority of those who took part in the discussion upon Mr. Mordey's paper, which appeared to show that capacity-current losses in high tension are practically *nil*, I still think that the cost of generating current for charging cables is a very serious item of expenditure in many alternate current stations.

At Hastings, for instance, between the hours of midnight and 4 p.m. during the past year we have generated 188,000 volt-ampere units, and for this purpose have used about 840 tons of coal. The above output may be analysed as follows:—

Useful work	94,600 units.
Exciting transformers	35,000 „
Capacity current	58,400 „
Total	188,000 units.

Now, I am convinced that if we had no high tension cables to charge, but merely had to generate the 129,600 actual units per annum, we should not use more than 10 lbs. of coal per unit generated. On this basis the actual units generated would account for a coal consumption of 579 tons per annum, leaving 214 tons, costing £359, to be accounted for. This, we believe, represents the annual cost of charging the high tension cables during the hours of light load. Whether it is wasted in dielectric hysteresis, or whether it is entirely due to the fact that for several hours per day we have had to run larger, and, as it so happens, less economical plant than would have been needed for generating the actual units, is not known. I merely wish to show that ours is a case in point where the generation of capacity currents does apparently cost between £300 and £400 per annum. Mr. Andrews.

We have for some time been taking steps to prevent the above loss by arranging our system of distribution in such a manner that it will be possible to disconnect the whole of the high tension feeders and transformers during the hours of light load, and feed the few consumers we have on at that period through the low tension distributing mains. When we have this completed, we shall be able to run for a week with our high tension feeders connected, and for a week without, and so be able to make careful comparisons which will show us the actual cost, under working conditions, of generating capacity currents.

Mr. W. DUDDELL (*communicated*): As I am responsible for the statement in Mr. Minshall's remarks that the Swinburne wattmeter, used in the tests marked thus †, was specially calibrated on a power-factor of 0·1, I should like to make a correction. The wattmeter itself was tested on a low power-factor and found satisfactory; but *the wattmeter in conjunction with the 20,000 ohms series resistance, as used by me at Croydon, was not so tested*. The 20,000 ohms resistance consisted of two 10,000 ohm coils made by Mr. Swinburne and wound in the manner described by him at the meeting. Mr. Duddell

In trying to find out whether the high power-factor of the Croydon cable was due in any way to its apparently low insulation resistance, I tried the effect of varying the frequency, when I noticed that at very low frequencies there was a distinct clicking sound in the 20,000 ohm resistance, which I traced to a brush discharge occurring between the layers of wire on the coils at each peak of the wave.

This brushing, which I noticed at the very low frequencies, may also be taking place at the ordinary frequencies, and leads me to doubt the accuracy of the tests taken with this Swinburne wattmeter when using the 20,000 ohm resistance in series with the P.D. coil. Further experiments have shown that the wattmeter always reads too high when used, with these particular coils, to measure the power supplied to a circuit in which the current leads, even when no brushing occurs, owing to the capacity effect between the different layers of the coils.

Mr. Mordey and Mr. Mather have both drawn attention to the effect of wave form on the capacity current of the cable, and it is interesting in this connection to note that when using alternators having wave forms very different from a sine curve, such as those at Croydon, the frequency of the cable current is several times the frequency of the

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This brushing, which I noticed at the very low frequencies, may also be taking place at the ordinary frequencies, and leads me to doubt the accuracy of the tests taken with this Swinburne wattmeter when using the 20,000 ohm resistance in series with the P.D. coil. Further experiments have shown that the wattmeter always reads too high when used, with these particular coils, to measure the power supplied to a circuit in which the current leads, even when no brushing occurs, owing to the capacity effect between the different layers of the coils.

Mr. Mordey and Mr. Mather have both drawn attention to the effect of wave form on the capacity current of the cable, and it is interesting in this connection to note that when using alternators having wave forms very different from a sine curve, such as those at Croydon, the frequency of the cable current is several times the frequency of the

Mr. Duddell. alternator, according as one or the other of the higher harmonics of the wave form supplies the larger part of the cable current; so that it is impossible completely to compensate the capacity current by means of a choker. This is probably the reason why the observed alternator current, when supplying cable and choker in parallel, even when adjusted to the best conditions, is generally much larger than the calculated value.

Professor Ayrton. Professor W. E. AYRTON (*communicated*): Reference has been made in the discussion to employing, as a check on the measurement of the power wasted by a cable in dielectric hysteresis, the measurement of the power required to drive a direct-current motor which was itself geared to the alternator that was charging the cable. Such a relatively cumbersome method, however, is wholly unnecessary in the case of the tests carried out by Mr. Mather, since, in consequence of the methods which he adopted being such as to bring the current which he supplied to the whole arrangement nearly into phase with the P.D., a fairly exact value of the total power can be obtained from the readings of the ammeter and voltmeter alone.

The following figure represents one of the many tests carried out on February 12th at the works of the British Insulated Wire Company, Prescot :—

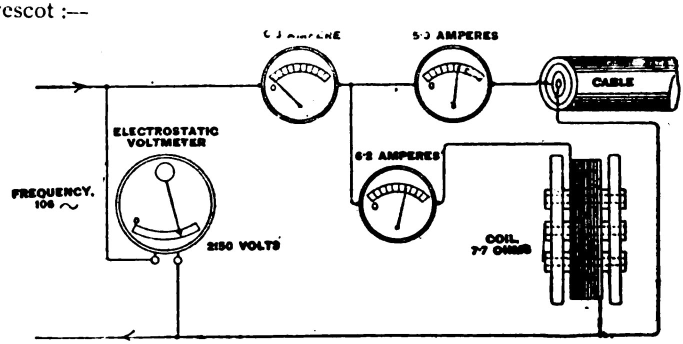

FIG. Q.—Current Supplied less than One-Fortieth of the Sum of Currents in Branches.

Now the total power given to the cable and to Mr. Mather's choking-coil *could not have exceeded* 0·3 × 2,150 or 645 watts. The power given to the coil alone *could not have been less* than $\overline{6{\cdot}2}^2 \times 7{\cdot}7$,* or 296 watts. Hence the power given to the cable *could not possibly have exceeded* 645 − 296, or 349 watts.

The volt-amperes for the cable were obviously 2,150 × 5·9, or 12,685; hence the power-factor of the cable *could not possibly have been larger* than $\frac{349}{12,685}$, or 0·028.

This value, 0·028, is, of course, an outside limit, and therefore is higher than the actual power-factor 0·024 published by Mr. Mather for

* This resistance was measured, with a Wheatstone bridge, just before and just after the experiment in the figure was made.

Professor Ayrton.

this paper cable, but that the two values differ so little is a striking proof of the accuracy of Mr. Mather's figures.

In my remarks made on the 10th of January I promised that I would construct a coil *without iron* which, under Mr. Mordey's conditions as regards capacity, frequency, and P.D. should waste far less energy than did his choker, and should be able to reduce the current in the supply leads to a fraction of the least value which he was able to arrive at. Comparing the readings of the instruments in the preceding figure with those in Fig. 4, page 378, of his paper, and referring to the particulars of the weights of their coils given respectively by Mr. Mordey and Mr. Mather, we see that the comparison is as follows :—

	Mordey.	Mather.
Least current in supply leads, amperes...	1·6	0·3
Power in watts wasted in choking-coil	500	296
Weight in pounds of complete choking-coil	260	92·5

Mr. Sparks has told us that in carrying out the test described in Mr. Mordey's paper, the energy-meter rotated *backwards* when applied to the cable. To be logical, therefore, Mr. Mordey ought to have concluded that a cable was a *source of energy*. But I presume that whether the meter ran forwards when applied to the choking-coil alone, or backwards when joined with the cable alone, the reading was in each case assumed to measure energy *given to* the coil or cable respectively.

Directly, however, that the proof of Mr. Mordey's paper was sent out, and before the paper was read, some of us suspected that the energy-meter in his experiments did run *backwards*. And so Mr. Evershed, Mr. Mather, Mr. Duddell, and myself considered independently what an energy-meter attached to a cable really indicated when it ran backwards; and the result, which has been tested experimentally in my laboratory, is as follows :—

Let h and o be the self-induction, in henries, and the resistance, in ohms, of the pressure coil of an Elihu Thomson energy-meter, that is of the armature, starting coil, and so-called non-inductive resistance; then such a meter attached to a cable, as in the accompanying figure

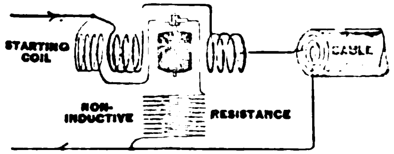

FIG. R.—Thomson Energy-Meter.

Professor Ayrton.

and supplied with current following the sine law, *will rotate forwards, or will not budge, or will rotate backwards, according as the true power-factor of the cable exceeds, or is equal to, or is less than,* $\frac{hp}{o}$.

Hence, apart from the rate at which the energy-meter runs backwards, or the voltage applied to the cable, or what current may flow into it, the mere fact that the meter *does* run backwards proves, with sine waves, that the ratio of the *true* power to the volt-amperes, that is the *true*

power-factor of the cable, is *less* than $\frac{hp}{o}$.

Next, measurements were made on four modern specimens of Thomson energy-meters, for the loan of three of which I am indebted to the British Thomson-Houston Company. And the following were the results obtained :—

No. 62,695	$h = 0{\cdot}25$ henry	$o = 3{,}785$ ohms.
" 230,355	$h = 0{\cdot}24$ "	$o = 2{,}100$ "
" 230,375	$h = 0{\cdot}26$ "	$o = 3{,}060$ "
" 230,380	$h = 0{\cdot}22$ "	$o = 3{,}095$ "

Hence, if the meter illustrated in Fig. R be the first one in this list, for example, and if, when a sine wave current of 100 ∿ be applied, the meter be found to run *backwards*, then, no matter at what speed it may run backwards, or what may be the value of the voltage applied to the cable, or the current flowing into it, the *true*

power-factor of the cable is *less* than $\frac{0{\cdot}25 \times 628}{3{,}785}$,

i.e., is *less* than 0·042.

And this limiting maximum value, curiously enough, is not so very much greater than the actual value found by Mr. Mather for this County of London cable, viz., 0·029.

Further, it can be proved that the *faster* the energy-meter is found to run *backwards* the *smaller* is the *true* power-factor of the cable, that is, the less is it compared with this limiting value 0·042.

If instead of an energy-meter, a simple wattmeter be employed, then for running forwards, staying at rest and running backwards, we have merely to substitute a positive deflection, deflection nought, and a negative deflection. So that with a simple wattmeter applied to a cable which is supplied with a sine wave current, the wattmeter will give a *negative* deflection (as obtained, for example, by Dr. Sumpner), when the *true*

power-factor of the cable is *less* than $\frac{hp}{o}$,

h and o now referring to the fine wire circuit of the wattmeter.

As the preceding energy meters can only be employed directly on circuits with a pressure of 200 volts or less, it is most probable that Mr. Mordey, in his tests, used some form of step-down transformer, the effective inductance and resistance of which would have to be included in the preceding formulæ. But no information has been given, either in the paper or in the discussion, regarding the size, shape, resistance.

or inductance of the transformer, nor are we even told whether such a step-down transformer was actually employed. Professor Ayrton.

Mr. Sparks was not present at the meeting on the 10th of January, and so has been misled into thinking that on that occasion I said that if measurements were accurately made with the County of London Cable, the value found for the "loss of energy would be one-tenth of the figure given." No such statement is contained in the shorthand writer's official transcript of the verbatim report of my remarks, nor is there any such statement in the account of the discussion as given in the technical press at the time.

Perhaps Mr. Sparks had in his mind what I said about the value of the power-factor, 0·01, found some years ago in my laboratory for the Swinburne butter-skin condensers. If so, it is interesting to note that Mr. Swinburne now remarks that this value, 0·01, is not lower, but considerably *higher* than he himself found for the same type of condenser.

Mr. W. M. MORDEY, in reply: I will not detain you whilst I attempt to reply to all the speakers: I will make one or two observations only I am very glad the last speaker, Mr. Minshall, has given his experience, especially as in his tests of the 5,000-volt Croydon cable he has been assisted by Mr. Duddell. His power-factor of 0·1 is very near my own, and supports the belief that there are appreciable losses in cable dielectrics. A further practical confirmation has reached me from Mr. Kapp, our old member, who has written me from Germany, giving a singular confirmation. They find high-tension three-phase cables in Germany get appreciably warm on light load. An appreciable warmth, of course, means a good deal of power. Such an observation is very important. We have been told by Professor Fleming that we must use a motor generator test. We have done so. Mr. Sparks has used a motor generator test, and Mr. Minshall has, and they have found a large addition of power required to drive the motor when the cable was switched on. This method Mr. Sparks shows, also gives a power-factor of more than 0·1. Mr. Mordey.

I should like to recall a statement made by Mr. Swinburne about ten or eleven years ago at the Physical Society (see *Electrician*, Dec. 19, 1900), when he said that from his calculation of the losses in paper condensers, the loss in Deptford paper mains from dielectric hysteresis would be about 7,000 watts. Curiously enough, Mr. Partridge, who did not know of this, and who is the engineer of the Company, assures me that the loss in these cables is quite 1,000 watts per mile, or exactly the figure that Mr. Swinburne gave ten years ago. Some of the figures given, even the figures that have been quoted by Professor Ayrton from Lombardi and Cardew, confirm me to a certain extent; they are in the same order. Lombardi's results come out at 0·068. That is in the same order as the losses that I am considering. It is not, as Professor Ayrton and others have tried to show, a mere fraction of that amount—a mere negligible amount undeserving of serious consideration. With some kinds of cable the power-factor may be lower, and with other kinds of cable it may be much more. Another point: cable makers have told me that they have often had

Mr. Mordey cables which on light load got quite warm to the touch, simply from dielectric hysteresis—cables that have a good insulation resistance.

We have had an exceedingly useful discussion, I consider, to-night. Quite possibly I may turn out to be wrong to some extent. For the sake of the industry I shall rejoice to find that I am very much wrong. Of course I need not say that I shall be very sorry for personal reasons if I have made a big mistake. I do not think I have. There are many practical indications that I have not—such, for example, as the known and considerable vibration of alternate-current cables. Such a vibration can hardly occur in a heavy cable without considerable loss of power.

May I say that I never claimed for one moment that the power-factor found in that cable, and now apparently confirmed by the motor generator method, was of a universal application. I repeatedly took pains to guard against such an impression. I knew, of course, that I was building general conclusions on the results of one test, and I repeatedly stated in my paper that *if* the results I got were correct, and *if* they applied to other materials and other kinds of cables, the loss of energy would be as I made it out to be.

I want to repeat my thanks to many speakers, especially to Mr. Sparks, who took up the subject as a serious engineering matter, and in his Company's interest made as full an examination as he could with the unusually complete means at his disposal. Personally I am very much obliged to him, and I think the Institution ought to be very much obliged to him for the trouble he has taken in this matter. I beg to thank the gentlemen who have done me the honour to speak on the paper, and I hope to deal with their remarks later on.

[*Added by Author.*]—I am very much gratified to find that my paper has brought out such a mass of useful information. The contributions to the discussion seem to me to be very valuable. It would not be possible for me to deal with them in any detail, even if I were able to do so. Fortunately most of them can stand by themselves as useful additions to the knowledge of the subject apart from their relation to my paper. I have already alluded briefly to Professor Ayrton's contribution. He misquoted Cardew and Lombardi in his effort to prove that I did not agree with him. I have pointed out that his claims to early knowledge must not be taken very seriously, seeing that up to the reading of my paper he never realised the very great importance of wave form in questions of capacity current, but boasted of having for ten years used (presumably for teaching purposes) methods which are now known to be quite unreliable in practice. Although right enough on the blackboard, they were wrong by two or three times (or by two hundred or three hundred per cent. as he would picturesquely describe it) in practical applications. From Mr. Sparks' remarks I learn that in another test case Professor Ayrton was hopelessly wrong. He pointed out with great emphasis that my choking-coil arrangement for reducing capacity current generated by the alternator was very imperfect inasmuch as it only reduced the current from 6 amperes to 1·6 amperes, and he offered to supply a choking coil which would reduce it to 0·07 amperes. Professor Ayrton points out that the proper method was all clearly given in a paper by him

before the Physical Society in 1891, and he proceeds to criticise my result thus (quoting from the shorthand report): "But now if we take Mr. Mordey's own experiment, I say that by dealing with the actual values given in that paper without going a step further—and that is the best proof of what was in that paper—I can enormously improve his result." He then shows that the current will be reduced to 0·07 by his coil instead of 1·6 by mine. Well, Mr. Sparks has told us that Professor Ayrton made this test with his own coil and brought the current down not to 0·07, but to 2·7 amperes. **Mr. Mordey.**

Thus, instead of reducing the current to about 4 per cent. of mine, by his coil he made it about 70 per cent. greater than mine—a forty-fold error—or as Professor Ayrton would express it, an error of four thousand per cent. Truly as he says, "Without going a step further, that is the best proof of what was in that paper."

It is, perhaps, unfortunate that on these two simple matters the tests which have been made have been so entirely against Professor Ayrton's conclusions. It has rather discouraged me from considering the rest of his communication as carefully as it no doubt deserves; but at least it stands in the Journal for reference.

Professor Ayrton's further communication (p. 460) is a filling out in great detail of what I pointed out briefly at p. 378—viz., that if a choking-coil be used to balance the capacity, and if the balance is perfect, then the alternator will be working with a power-factor of unity. Professor Ayrton shows that the watts cannot be greater than the volt-amperes.

Mr. Sparks' account of the tests that have been made on his cable will be read with interest by all who may wish to study this matter seriously. The discrepancies obtained in the dielectric losses show the difficulty of the subject. The motor-generator tests seem to fully confirm the original wattmeter tests. If they are too high, it can only be because of eddy current losses in the generator due to the charging current. This source of error would be eliminated or reduced by using a choking coil to balance the capacity so as to reduce the charging current required to be produced by the generator.

Mr. Sparks' observations on the discrepancy between the calculated and the observed capacity current confirms what I have already said, and further emphasises the need for stating definitely what is meant by the term "power-factor." As the "apparent watts" may vary enormously while the true watts remain fairly constant, it is evident that the term power-factor must be used with caution, otherwise misleading comparisons may be made.

I am glad Mr. Sparks has brought out so clearly the practical importance of dielectric hysteresis. He shows that even if the lowest power-factor found in the tests—the lowest of Professor Ayrton's or Mr. Mather's results—is the correct one, the annual loss on his cable will be 155,000 units, or 8·3 per cent. of the total units delivered. At a penny a unit this amounts to £645 a year, or a capitalised value, at 5 per cent., of £12,900. Mr. Sparks very properly points out that with another kind of dielectric the loss might be only one-third of this. True, but do not let us forget that with a two-phase cable the loss

Mr. Mordey. would be doubled, and with a three-phase cable it would be increased to three times that of a single-phase. This difference between single and multiphase working seems to merit some attention.

It is to be feared that Mr. Sparks' remarks support the view that dielectric hysteresis, considered practically, is a cause of serious loss and is deserving of careful attention.

Dr. Fleming's former connection with the Deptford system makes his remarks especially interesting to me. Knowing the great difficulties of wattmeter measurements under the conditions dealt with in my paper, he prefers a simple motor-generator test to any purely instrumental methods. He thinks such a test must give accurate results. It will interest Dr. Fleming to see that Mr. Sparks' motor-generator test, as well as that of Mr. Minshall, fully confirms the large power-factor. If the motor-generator result is not entirely accurate, it must be, as I have pointed out above, that the capacity current causes reactions in the generator which lead to losses in eddies and magnetic hysteresis.

I am interested in Dr. Fleming's account of his own efforts to measure the losses in the Deptford cables by taking indicator diagrams of the engine with various lengths of cable in circuit, but I am afraid I cannot agree that the method is likely to give accurate results. The engines available were of large size, and their indicator cards under very light-load conditions would be of such a character that it would be practically impossible to detect the small power mentioned by Dr. Fleming.

In connection with the Deptford mains, I have the permission of Mr. G. W. Partridge, the Company's engineer, to state that the actual loss of power in their mains is about 1 kilowatt per mile. As there are 28 miles of mains, having a capacity of about $\frac{1}{3}$ mfd. per mile, this works out for the 28 miles at 10,000 volts 87 ∿ to 18,215 apparent watts per mile (assuming sine-curve E.M.F.), and on Mr. Partridge's figure of the true loss to a power-factor of 0·055. If the whole 28 miles were always in use the annual loss would be 245,280 units. Mr. Partridge, however, reduces the loss to much less than this by reducing the number of mains in use during hours of light-load, thus saving both the true loss and the indirect losses due to the production of "wattless" current. This, it will be seen, would require fully 500 k.w. of plant unless compensated in some way.

Dr. Sumpner says I should state the dielectric loss as a percentage of the load the cable is to transmit. To do that one must know the load. Dr. Sumpner works out the County Company case and makes the loss something between $\frac{1}{4}$ per cent. and $1\frac{1}{2}$ per cent. Mr. Sparks, the engineer to the Company, works it out from a practical knowledge of the load and assuming the lowest power-factor obtained in any test referred to in this discussion, and finds the loss will be 8·3 per cent.

Let me give a practical case that has just come under my notice. A 50 ∿ 10,000-volt three-phase cable, 10 miles long, is proposed as a means for supplying a lighting load having a maximum of 200 k.w. and a load-factor of 12 per cent. The cable is expected to have a capacity

Mr. Mordey.

of 0·3 mfd. per mile. Assuming a power-factor of only 0·025 (or lower than any one has yet found in a cable), the dielectric loss will be 24 per cent. of the units transmitted. This, of course, shows how unwise it would be to use such a cable for such a load.

I am much interested in Dr. Sumpner's remarks on transformers in connection with wattmeters, although I am afraid I do not altogether follow his argument. He refers to his use of a large transformer "very under-loaded," but surely he knows—what Dr. Fleming taught ten years ago in his well-known paper on transformers—that a transformer fairly well loaded had a power-factor of 1, and kept it up to full load. It was for that reason that in arranging my wattmeter I purposely

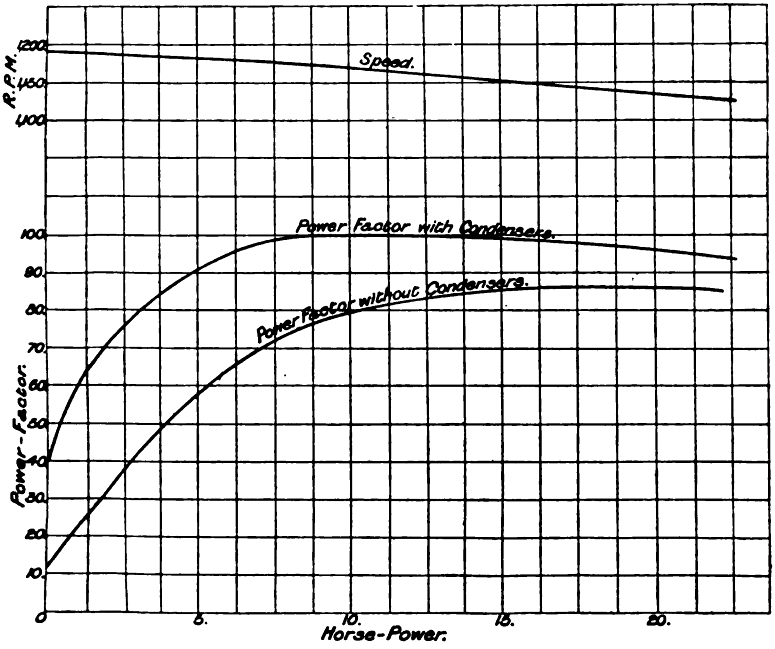

FIG. S.

made the short-circuited suspended secondary of such a character that the transformer was fully loaded.

Mr. Swinburne, in his remarks, is interesting and suggestive as usual, but I do not think there are any points that call for a reply from me. Mr. Swinburne made gallant efforts to introduce condensers into practical use a good many years ago; it will interest him and others to know that Mr. Wm. Stanley, the well-known American electrical engineer, is supplying condensers in considerable quantities for improving the power-factor of alternate-current motors. Mr. Stanley informs me that there must be over 100,000 H.P. of motors working in that way in the United States, and he sends me some interesting

Mr. Mordey. curves showing results, one of which I give here (Fig. S). The importance of this result will be at once recognised.

I have discussed with Mr. Stanley the questions raised in my paper, and learn from him that there are very considerable dielectric losses in many cables, and that the reduction of those losses in the dielectric of his condensers occupied him for a very long time. He eventually succeeded in his efforts to make condensers on a commercial scale, in which the losses are very small. The very slight heating of the condensers is a proof of this.

From another eminent American electrician, Mr. Steinmetz, I hear indirectly that in at least one "extra high tension" transmission line in the United States where there is some underground cable it has been found that there is a serious dielectric loss.

Mr. Mather seems to have gone very fully into several of the points raised in my paper, and is apparently of Professor Ayrton's opinion that my paper is only useful as a text for a paper of his own. For my part I am satisfied even to be a humble text, if by that means I can bring out such useful sermons. But the tone of the sermon is not conducive to discussion, so I gladly let it stand on its merits, which are considerable.

Mr. O'Gorman suggests that the heating of the cable mentioned by Mr. Kapp may be due to local failure of insulation on the outer layers of the cable, and that the heat may only be on the outside, the cable not being heated throughout. This would not affect the result. All the heat, however generated, must get out by the surface, and under long continued working the surface temperature would be the same for the same loss of energy, whether the heat came from the centre or the outside of the cable.

Mr. W. E. Gray refers to several points of great interest on which at present there is very little available information, such as the variation of capacity, and the effect on capacity of treatment of the dielectric during manufacture, and the possibility of getting low capacity with rubber or high capacity with materials that are supposed to have a low specific capacity. I can confirm a part of this even from my own small experience, as I came across a large paper-insulated cable, quite recently supplied, which had quite as high a capacity as the rubber cable on which my tests were made. Apparently the kind of paper and the material used to permeate the paper affect the result very considerably. Now that this subject has come up in a practical way it is to be hoped that we shall gradually get more knowledge on the essential points, and gradually reduce any causes of loss that may be under control. Cable makers will gladly co-operate with engineers to this end. I can say this with confidence from the way Mr. Gray and other cable makers—Messrs. Glover's, Messrs. Siemens, and the British Insulated Wire Co.—endeavoured to help me in my efforts to collect information on the points I have been trying to elucidate.

Mr. Threlfall seems to be one of the very few men who have worked successfully at the construction of condensers capable of standing high pressures. His remarks will be read with interest. He objects to my ascribing the energy losses to dielectric hysteresis, but he does not

Mr. Mordey.

help me much, as one of his conclusions is that "the cause of the dissipation of energy is not known." I gather that, like Mr. Swinburne, Mr. Threlfall thinks part of the loss may be due to a kind of conduction. This is a question of pure physics, on which I fear I am not very competent to speak, but I would refer Mr. Threlfall to the passages near the end of my paper where I tried to express a similar view. I point out that the energy component of the capacity current "in all practical essentials is a leakage current: it goes right through the dielectric, and heats it in its passage exactly like a leakage current." (See p. 383.)

I used the term "dielectric hysteresis" under compulsion, as the only current electrical term to cover broadly the dissipation of energy in insulating materials, but I do not like it, and much prefer to use a non-committal term, such as "loss in the insulation."

Mr. Minshall's tests at Croydon tend to confirm the serious character of the dielectric loss. I almost wish they did not, as it would then be easier for me to say that I think we have in Mr. Minshall a man of exceptional ability and knowledge. His experiments are very interesting and very important. The effect of capacity in increasing the current is new to me. On that and other points many of us would be glad to hear more. I hope this Institution will obtain from him a full account of the work of which in this discussion he has given only enough to excite our curiosity.

Mr. Fricker's suggestion that dielectric losses should be taken at different periodicities will, I hope, be acted on. The pendulum illustration seems an apt one.

Mr. H. M. Sayers' experience of breakdowns and their reduction by change of frequency is very interesting and important. As very few people have had a wider practical experience than Mr. Sayers, his remarks on possible causes of cable breakdowns and on other matters will be found useful and suggestive.

Mr. Stuart A. Russell's conclusion from an examination of Professor Ayrton's paper on "Interference with Alternating Currents," is the same as my own. It appeared to me to be a collection of undigested purposeless experiments that at the time taught nobody more than it taught its author. Mr. Russell is also correct in pointing out that in 1891 neither Professor Ayrton nor any one else in the discussion on Dr. Fleming's paper showed that it was not necessary to go on generating to 45 amperes capacity-current at 10,000 volts.

Mr. Esson is in reality in agreement with me about the "Ohm's law" of the relation between pressure and capacity. The formulæ quoted as showing pedagogic knowledge of principles are based on nothing more substantial than a supposed necessity for some basis for blackboard calculations. I quite agree with Mr. Esson—these relations are "very imperfectly understood." It is worse than mischievous to express them as laws.

In *Mr. Alexander Russell's* remarks on the different wave effect of condenser and choking coils, he illustrates once more the difficulties of getting a perfect balance. He suggests that condensers should be reduced in size by transforming up; this seems sound, but I cannot

Mr. Mordey. find that it is ever done. I wonder why. It ought to be useful with low-tension motors.

Mr. Addenbrooke thinks the Board of Trade should allow overhead wires. Probably they would be allowed for crossing quite open country, but we are not likely to see them again in towns. His tests on losses in condensers are interesting, but not necessarily any guide to losses in cables. There seems little doubt that condensers may be made with very small losses. But if the same care were applied to cable-making, the price of the cable would probably go up very much.

Mr. Addenbrooke's researches seem to have covered a very large field during the last few years, but I can only refer to a few of the points he raises. We must make shift with cables, as it is pretty certain the Board of Trade will not allow overhead wires, except, perhaps, in the open country. The losses in condensers are probably very little guide to what occurs in cables. Even if the materials are the same, the methods of manufacture are not.

The choking coil took a current of about 0·15 ampere. I did not measure it very carefully. The eddy current losses in chokers with open gaps seem to be considerable. They disappear when the gap is closed. I think I explained that I used an iron choker with a gap to be able to put it in a reasonable-sized iron case. For practical purposes the external field of an ironless choker is a difficulty—and it is not adjustable easily.

Mr. Boot confirms my observations as to the checking of an engine when an idle cable is switched on. I hope he will find an opportunity of making the steam tests he mentions. His estimate of the cost of wattless current as about one-fourth of wattful current is about the same as my own. He has no doubt given the right explanation of the change produced on his power-factor by increase of length of cable.

Mr. Nisbett speaks as a practical cable maker. I am very glad he is taking such a keen interest in this matter. No one has better opportunities for experiment and investigation. Whatever result my paper may have, it cannot be an ill one for paper cables. Mr. Nisbett says Deptford could not lose much energy in its mains without knowing it—therefore the power-factor must be low. But Mr. Partridge has told me that he has found considerable losses in his idle mains, and therefore only keeps enough of them in circuit for the load. Then it must not be forgotten that in an ordinary alternate-current station a difference of 30 per cent. often exists between the "units generated" and the "units sold." If this can occur at 2,000 volts, what may not happen at 10,000 or 15,000?

Mr. Nisbett inclines to the belief that the power-factor in his cables is about ·025. I hope he is right. Let us assume, for the sake of argument, that he is right; and let us further assume that he can make cables with the very low capacity of 0·25 mfd. per mile. What will this mean in a three-phase, 10,000-volt, 50 $\sim$ cable? It will mean a loss of 589 actual watts, or 5,150 B. of T. units per mile per year. At 1d. per unit this eats up £21 9s. a year. The loss would be the same as if 8-c.p. lamps were placed nine yards apart along the mains.

Mr. Nisbett works out the case of the Midland Power Company's

cables, and shows that assuming all the 5,000 k.w. of plant is taken up, the percentage loss will only be 1·2 per cent. He kindly sent me particulars of those same cables. I make the loss 1·5 per cent., but that is near enough. The basis of comparison seems rather a dangerous one from a business point of view. After all, it does not take many small percentage losses to absorb an ordinary dividend, and 1·5 per cent. is 30 per cent. of 5 per cent. Till the whole 5,000 k.w. is taken up it will be more than 30 per cent. of 5 per cent.! On the important question whether the power-factor diminishes or increases with increase of pressure, I note the difference of opinion between Mr. Nisbett and Dr. Hoor; but he does not give any reference to Dr. Hoor's results, which were not contributed to this discussion. The only test I have been able to make is that given in Fig. 1. The straightness of the "curve" suggests that the power-factor is constant at least for pressures up to 4,500 volts.

I quite agree with Mr. Nisbett that chokers to reduce capacity-current generated are only useful at times of light load. Unfortunately light load often occupies a large part of the day.

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Mr. Cruise's contribution to the discussion deserves careful study. As he is engaged practically in connection with extra-high-tension work his opportunities for obtaining information are probably considerable. As to the amount of the losses, Mr. Cruise is now in possession of all the information I can give him, and can very well form his own conclusions. He regards a loss of 9 or 10 per cent. as only "rather formidable," but thinks it would not quite spoil a dividend: I should have thought it would have wiped it out altogether. He assumes a large load and a high load-factor, and thinks it has been satisfactorily demonstrated that these things may reasonably be expected. He assumes that in power schemes 2,500 k.w. per cable will be common. I quite agree with him that if all these desirable conditions are obtained all will be well. He builds his hopes on it, but admits that if it does not come off—if the distribution is largely by cables supplying 500 k.w. or less—then the losses will be disastrous. I fear he is quite right, and can assure him that they become very serious indeed even with such low power-factors as 0·025.

He puts the "other transmission losses" at 5 to 7 per cent. For my part I should be very agreeably surprised if the other transmission and transformation losses come out at less than 20 per cent.

Mr. Cruise's table is both useful and interesting.

Mr. Baillie makes the useful suggestion that cable makers should endeavour to take the energy loss by observing the rapidity of polarisation, and points out that they have all the facilities for doing this in making their insulation tests. Mr. Baillie points out that Lombardi's power-factor of 0·068 was got on a cable and not on a condenser. It was a gutta-percha cable—the only one referred to in this discussion.

Mr. Whalley is quite right. My attention was first called to this capacity matter by the study at St. Petersburg of some effects occurring

Mr. Mordey. find that it is ever done. I wonder why. It ought to be useful with low-tension motors.

Mr. Addenbrooke thinks the Board of Trade should allow overhead wires. Probably they would be allowed for crossing quite open country, but we are not likely to see them again in towns. His tests on losses in condensers are interesting, but not necessarily any guide to losses in cables. There seems little doubt that condensers may be made with very small losses. But if the same care were applied to cable-making, the price of the cable would probably go up very much.

Mr. Addenbrooke's researches seem to have covered a very large field during the last few years, but I can only refer to a few of the points he raises. We must make shift with cables, as it is pretty certain the Board of Trade will not allow overhead wires, except, perhaps, in the open country. The losses in condensers are probably very little guide to what occurs in cables. Even if the materials are the same, the methods of manufacture are not.

The choking coil took a current of about 0·15 ampere. I did not measure it very carefully. The eddy current losses in chokers with open gaps seem to be considerable. They disappear when the gap is closed. I think I explained that I used an iron choker with a gap to be able to put it in a reasonable-sized iron case. For practical purposes the external field of an ironless choker is a difficulty—and it is not adjustable easily.

Mr. Boot confirms my observations as to the checking of an engine when an idle cable is switched on. I hope he will find an opportunity of making the steam tests he mentions. His estimate of the cost of wattless current as about one-fourth of wattful current is about the same as my own. He has no doubt given the right explanation of the change produced on his power-factor by increase of length of cable.

Mr. Nisbett speaks as a practical cable maker. I am very glad he is taking such a keen interest in this matter. No one has better opportunities for experiment and investigation. Whatever result my paper may have, it cannot be an ill one for paper cables. Mr. Nisbett says Deptford could not lose much energy in its mains without knowing it—therefore the power-factor must be low. But Mr. Partridge has told me that he has found considerable losses in his idle mains, and therefore only keeps enough of them in circuit for the load. Then it must not be forgotten that in an ordinary alternate-current station a difference of 30 per cent. often exists between the "units generated" and the "units sold." If this can occur at 2,000 volts, what may not happen at 10,000 or 15,000?

Mr. Nisbett inclines to the belief that the power-factor in his cables is about ·025. I hope he is right. Let us assume, for the sake of argument, that he is right; and let us further assume that he can make cables with the very low capacity of 0·25 mfd. per mile. What will this mean in a three-phase, 10,000-volt, 50 $\sim$ cable? It will mean a loss of 589 actual watts, or 5,150 B. of T. units per mile per year. At 1d. per unit this eats up £21 9s. a year. The loss would be the same as if 8-c.p. lamps were placed nine yards apart along the mains.

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Mr. L. Andrews is very much to the point in showing that the charging of his mains is costing him between £300 and £400 a year. He has gone so far as to rearrange his system to avoid this loss during light-load hours. I hope he will not forget to let us have the result of the comparative tests he intends to make when he gets his arrangements completed.

Conclusion.—It would require a great deal of time and space to do justice to the discussion. I have only been able to touch on some of the salient points. I am greatly obliged to all who have contributed to the elucidation of this subject. A mass of very useful additional and critical matter has been provided.

Attention has been directed chiefly to the loss of energy, and on the whole with a very useful result.

One object of my paper was to show that in the dielectric of cables losses were being entirely overlooked which were of engineering importance. I went so far as to say these losses were often more important than the copper losses. I gave the results of certain tests which may or may not have been correct. Similar values have been got on other cables by other people—capable observers like Mr. Minshall and Mr. Duddell. My tests have been disputed, but it has been shown by Mr. Sparks, the engineer of the company working the cables, that even on the basis of the lowest results obtained by later tests, this dielectric loss consumes more than 8 per cent. of the energy transmitted by the cables in question—that is to say, actually more than the copper loss. Since the discussion I have had occasion to go into the details of a power transmission scheme, and I find, so far from the dielectric losses being insignificant and unworthy of consideration, that on the basis of the lowest and latest values obtained by my critics, the dielectric losses will amount to considerably more than the copper losses. My study of this matter shows its very great and serious importance, especially in connection with "extra-high-pressure" schemes of transmission. In my paper I may or may not have been right as to the amount of the loss—that is not the essential point; the practical question is whether the loss is one which will affect practical engineering problems. I find that even on the most favourable assumption the loss is sufficiently serious to affect the way we must regard such problems in high-tension work as the choice of pressure, of frequency, of number of phases, of type, material, size, and construction of cables, of amount of load per cable,

In more than one of these things this loss will be found to be the controlling factor. Mr. Mordey.

The PRESIDENT: We have already thanked Mr. Mordey for his paper, but may I ask you again to give your thanks to him for his contribution? The President.

The motion was carried with acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates had been duly elected:—

Members:

Arthur Jacob.
Major-General Beresford Lovett, C.B., C.S.I., R.E.

Associate Members:

Stuart Bell.
Albert Campbell, B.A.
Alfred George Cooper.
Frank Little.
Edward John Neachell.
Charles Frederick Smith.
Albert Thomas Turney.

Associates:

Ernest Edward Allen.
Edward Harold Atkinson.
Alfred H. Cahen, B.Sc.
James L. Chambers.
Oliver Hammond Ellis.
Harold William Firth.
Charles William Forster.
Archibald Ernest Grant.
Charles Harold Higgins.
Frederick Walter Shorrocks.
Shelley Albert Stammwitz.
Charles Stewart, B.Sc.
Herbert Osborn Wraith.

Students:

Benjamin Baily.
Herbert Sugden Binns.
Joseph John Fasola.
Fred. E. Green.
Frank Clements Knowles.
John Ormiston McLaren.
Reginald Phillips.
Edgar Lloyd Smith.
George Edward Smith.
William Henry Taylor.
Sidney Mark George Teal.
R. Elliott S. Turnbull.
James W. Wilson.

Note.—The Institution is indebted to the *Electrician* for the blocks of the Figures on pp. 389, 426, 427, 455, 456, and 457, and to the *Electrical Review* for those of the Figures on pp. 460, 461, in the discussion on Mr. Mordey's Paper.—ED.

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The Three Hundred and Fifty-Eighth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 21st, 1901—Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on February 14th, 1901, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that the list should be suspended in the library.

The following transfers were announced as having been approved by the Council, viz. :—

From the class of Associates to that of Members—

Edward Stanley Franklin.

From the class of Associates to that of Associate Members—

George Henry Corringham.
Frederic E. Nosworthy.

From the class of Students to that of Associates—

William James Cooper.
Edward Henderson Freeman.
Mendel Finkelstein.
Eustace Graham Sheppard.
Henry Sinclair Watson.

Messrs. H. J. Moysey and H. J. Hodges were appointed scrutineers of the ballot for the election of new members.

Donations to the Building Fund were announced as having been received since the last meeting from:—Messrs. J. R. Andrew, R. C. Barker, B. Balaji, R. J. Brown, H. H. Crockford, and C. W. Fourness, to all of whom the thanks of the meeting were duly accorded.

The PRESIDENT: The following resolution from the Newcastle Local Section has been received since our meeting last week :—

NEWCASTLE LOCAL SECTION. Resolution passed at the meeting of February 11th.

"That we, the Newcastle Local Section of the Institution of Electrical Engineers, express our grief at the death of our late Beloved Sovereign, Her Majesty, Queen Victoria, and our most loyal sympathy with our present Gracious Sovereign, King Edward the VII., and to request the Secretary of the Institution to forward the same to the proper quarter."

THE ELECTRICAL POWER BILLS OF 1900: BEFORE AND AFTER.

By WM. L. MADGEN, Member.

The difficulty of selecting a title to describe suitably a statement dealing with many considerations is a familiar one, and as I should wish to deflect discussion to more important questions, I will by way of preamble more particularly describe the scope and intention of this paper.

The intention, then, is to consider those conditions of our electrical industry which led up to the Electrical Power Bills of the past session, to describe briefly some of the main features of the Bills themselves, and to urge the Institution to determine what its attitude should be in face of the charges of backwardness continually being made in regard to the applications of electrical energy in this country.

To present a connected case it may be necessary to traverse a certain amount of ground well known to many of us; but it is in the hope that we shall be more firmly united in our struggle against the continuing legislative and other difficulties by which our path is sorely beset, that I ask you to review the situation this evening.

The new century has been acclaimed on all hands as the age of electricity, but every article on the subject in the magazines and daily press, and they have been many, appears to bewail the backwardness of this country in electrical enterprise.

The *Daily News*, in a leading article devoted to the recent visit of Mr. C. T. Yerkes, the American tramway magnate, suggests that now Mr. Yerkes is about to have his hand in on this side he might proceed to think out some magnificent scheme for enabling the people of

England, among other things, to work their factories and workshops by electricity!

The *Daily Graphic*, in an illustrated article describing electrical developments in northern Italy, notes that ". . . in one enormous industry there can be no doubt that we are far behind nearly every important country in the world. That industry is, in broad terms, the adaptation of electrical energy to the needs of man."

The *Daily Mail*, in a leader headed "Our Start in the Electrical Age," says: "In the twentieth century we find that our competitors are ahead of us in the utilisation and application of electricity. It is not to England that the foreigner comes for dynamos or electric tools or electric lifts or electric railway and tramway fittings. . . . Our streets are rarely lighted by electricity. As a motive power on our railways and tramways this new force has been as yet only occasionally employed, and the two or three electric railways of London are still a source of wonder to the inhabitants of our islands. All this is greatly changed from the day when we led the world. And whereas in the past we built the foreigners' steam railways, to-day the American is building, or proposing to build, our electric lines."

This article goes on to say that "it would be interesting to investigate the causes of our backwardness." The matter is, however, something more than "interesting," it is one that demands our most active concern.

Some of the indictments are more sweeping. It appears we are not all alone unhappy; the *Pall Mall* considers that "in every department of public life our methods are out of date. We feast on words and trade upon tradition. . . . We forget that, though the camel may exist for a period upon its own hump, the process cannot last for ever. We have been like Brahmins in our pride and Mandarins in our methods, and that is a bad combination." *Fielden's Magazine*, the militantly British, finds space for Sir W. H. Preece to say, *à propos* of the dangers of foreign competition, that "we are a foolish and conceited nation, and blind to our own deficiencies."

The above are a few examples of the reproach which has become familiar to most of us. It may be the habit of the British, "in the intervals of blowing our own trumpets, to

rush to the other extreme, and to needlessly belittle ourselves." It may be that "prophets of ill are for ever telling us of the decadence of our industries and of the rapid progress of our rivals," but there is no comfort for the electrical engineer in any such commonplace.

After the events of the past year there is little need to urge that the national sentiment is as sound among members of this Institution as in any part of the community, and the conclusion which has been forced upon us from all sides that the extent of our department of industrial work is far behind that of nearly every other important nation in the world, is sufficiently mortifying.

There may be some of us who find amusement in the comments of the daily papers on technical subjects, but it should be remembered that the articles we scoff at are read by thousands of those of our fellow-countrymen who make up those sentiments and influences which affect us seriously, and it seems full time that steps should be taken to place the responsibility for our backwardness where it belongs.

We shall have to take our own part, or we shall find the public ordering German plant with the same complacency as they purchase German pianos.

It has become the custom with some of us to devote occasionally a few weeks to the visiting of other countries to benefit by the experience gained there in the developments of electrical work, and thanks principally to the energy of our Secretary this practice has become organised, and a largely increasing number now have opportunities of taking part in these expeditions.

The reflections ensuing upon these visits have no doubt varied in depth, and in character, with the individual and the nature of his occupations.

One of our greatest science teachers, in his Presidential address which lives in our memory, referred in inspiring terms to the visit to Switzerland and the revelation it was to us. We were, he said, very much like what engineers of 1870 would have been if brought suddenly into a generating station, and attributed much, if not most, of our backwardness to our knowing too little theory.

I am inclined to the view that this lack of theoretical knowledge is an effect rather than a cause of our troubles. In Germany and Switzerland particularly we see a systematic

devotion to technical and scientific training, but the Americans have applied themselves rather less to the principles than to the applications of science, and it is the latter country which is probably the most in advance of us in electrical engineering.

It is unnecessary, however, to give occasion for a discussion on theory *versus* practice. I am sure we take it to heart that we have too little theory, and will loyally support those who are endeavouring to apply more scientific methods to our manufactures. I am more apprehensive just now concerning the scope for the employment of the young electrical engineer when he has been prepared by the most approved methods.

We have no feeling but cordial goodwill for those friends abroad who have made our visits so pleasant and instructive; but the reflections of many of us on our return have been those of indignation at the obstacles set in the path of our industry by the governing bodies of this country, and of resentment at the wretched waste of energy and enterprise which they have occasioned.

The electrical engineers of the United Kingdom are not to blame, and there is no occasion for any apology on their behalf. I am aware there may be those who are interested in the maintenance of old methods of working, and we have internal complaints now and again for which the Observatory at Kew may for the moment be taken as a symbol. But we can put such issues past us for the present, and consider whether it is not our duty to make a united effort to secure liberal measures of enfranchisement.

The position cannot be attributed to lack of ability or inventiveness on the part of British engineers. Some of the most important improvements have been worked out in this country, but our environment has been too much for them, and they have found their fullest practical application abroad.

One of the first electric tramways on a practical scale was put down in the north of Ireland by Lord Kelvin, Mr. Traill, and others, but the effect of the Act of 1870 which had been humorously entitled "An Act to facilitate the construction and to regulate the working of Tramways," has been disastrous to tramway enterprise in this country.

The principles of dynamo construction were worked out

at an early stage by the late Dr. John Hopkinson, whose share in the evolution of the three-wire system is also well known to us.

To Swan as much as to any other the world is indebted for the incandescent lamp.

In the early eighties, work of the utmost value was done by Ferranti and others on the details of alternating-current transmission.

It is unnecessary for me here to dwell upon the abundant evidence in support of this. It is registered for the most part in the Journal of the Institution, and much of it is recorded in the work of others on every continent.

What is the reason, then, that our electrical industry is behind that of nearly every important country in the world?

It is due in the first place to silly legislation by Parliament and to obstruction by the numerous local authorities entrusted with arbitrary powers. In the second place it is due to a class of quasi-officials and their associates to whose direct monetary advantage it is that an opposition should be entered to every project in which they are not employed.

There may be contributory causes, but to these, and others that flow from them, our chief difficulties may be assigned.

Ere this Institution was founded an obstacle had been prepared for us. In 1870 was passed the Tramways Act to which I have referred, and these are some of its leading provisions. A tramway cannot be authorised by Provisional Order without the consent of the local authority of the district. If the proposed tramway is to run through two or more districts, and consents have been obtained in respect of two-thirds of the length, the Board of Trade may upon inquiry dispense with consents for the remainder.

When the procedure is by Provisional Order, the construction of the line can be absolutely blocked by notice given in the prescribed manner by one-third of the owners, or of the occupiers, of the premises abutting upon the road where for so short a distance as 30 feet or upwards there would be less than 9 ft. 6 in. between the outside of the footpath on either side of the road and the nearest rail of the tramway.

The most onerous condition is provided in the notorious

section 43 by virtue of which the local authority can purchase a tramway at the expiration of twenty-one years from the date of the Order, or of any subsequent period of seven years, on the terms of paying the then value of the tramway, exclusive of any allowance for past or future profits of the undertaking, or any compensation for compulsory sale, or other consideration whatsoever.

We shall agree with Mr. Granville C. Cunningham, general manager of the Central London Railway, that "there is perhaps nothing that has done so much to prevent the relief of overcrowding and congestion as the Tramways Act of 1870. Its provisions in rigidly limiting the term of the concession to twenty-one years, and practically fixing the price at which the Municipality may take over the undertaking at something far below its value, have effectually checked the growth of electric systems."

If procedure by Special Act is resorted to, the Standing Orders of the two Houses require in like manner the consent of the local authority, so that the undertaking is not furthered in that respect and is equally liable to be bled for the purpose. The frontagers are given a locus to oppose, so that a small number of them are not so well able, through caprice or other motive, to prevent the construction of an important line; but the expense and risk of procedure by Special Act have been sufficiently serious deterrents.

I think the nett results will justify us in agreeing with Mr. Balfour Brown that this same Tramways Act was "a very silly contrivance indeed."

Consider the waste of energy and of enterprise in battling against such conditions, and whether it is any wonder our countrymen have to complain that we are lamentably behind the rest of the world in the cheap and rapid transport facilities afforded by electric traction.

We have[1] pleaded that there is no country in the world which would benefit more than our own by the provision of comprehensive electric tramway systems, or that stands more in need of them to relieve overcrowding, yet their introduction has been slow and halting, and carried out in the face of bitter opposition. Instead of lending a helping

[1] See particularly paper by Mr. Granville C. Cunningham, in the *Tramway and Railway World*, December, 1889.

hand, governing bodies seem to have thought they were doing the public a service by narrowing enterprise down to the scantiest possible outlets, and in some cases by establishing an effective blockade against it.

Twenty-six years elapsed—near upon a generation—and it was not until 1895 that the repose of the Board of Trade was disturbed—a body curiously constituted and still more curiously named—and it was found that something really must be done. A Commission was then appointed to consider the question of Tramways and Light Railways, and as a result of their report the Light Railways Act was passed in 1896, only four years ago. But this was only a tentative provision, it expires this year, and unless some measure of enfranchisement is passed, we shall be thrown back upon the Act of 1870, which remains effective upon the Statute Book.

The other great department of our domain, the general supply of electrical energy for industrial and domestic purposes, is even yet almost entirely governed by the Act of 1882, which was passed at a time when "the state of the art" was such that electrical energy could only be supplied economically for a distance of a mile to a mile and a half from the generating station.

In effect the legislation was made to match the fact that at least one separate station was then required for each town, and the Town Council was constituted the authority which could either undertake the work itself, or consent to the acquirement of the necessary powers by a company.

In either case the Act contemplated the local authority being the ultimate owner of the local undertaking. The clauses as to consent, the period and the terms of purchase, were inspired by the spirit of the Tramways Act of 1870, and the effect upon electrical engineering as a national industry has been equally disastrous. The result was a fiasco. What did Parliament then do? Nothing until 1888, when it climbed down in a half-hearted way—analogous to its performance in connection with the Light Railways Act—and passed another measure extending the purchase period from twenty-one to forty-two years, but leaving the onerous consent clause and the ridiculous terms of purchase as they were.

Until after the Act of 1888 we could do practically

section 43 by virtue of which the local authority can purchase a tramway at the expiration of twenty-one years from the date of the Order, or of any subsequent period of seven years, on the terms of paying the then value of the tramway, exclusive of any allowance for past or future profits of the undertaking, or any compensation for compulsory sale, or other consideration whatsoever.

We shall agree with Mr. Granville C. Cunningham, general manager of the Central London Railway, that "there is perhaps nothing that has done so much to prevent the relief of overcrowding and congestion as the Tramways Act of 1870. Its provisions in rigidly limiting the term of the concession to twenty-one years, and practically fixing the price at which the Municipality may take over the undertaking at something far below its value, have effectually checked the growth of electric systems."

If procedure by Special Act is resorted to, the Standing Orders of the two Houses require in like manner the consent of the local authority, so that the undertaking is not furthered in that respect and is equally liable to be bled for the purpose. The frontagers are given a locus to oppose, so that a small number of them are not so well able, through caprice or other motive, to prevent the construction of an important line; but the expense and risk of procedure by Special Act have been sufficiently serious deterrents.

I think the nett results will justify us in agreeing with Mr. Balfour Brown that this same Tramways Act was "a very silly contrivance indeed."

Consider the waste of energy and of enterprise in battling against such conditions, and whether it is any wonder our countrymen have to complain that we are lamentably behind the rest of the world in the cheap and rapid transport facilities afforded by electric traction.

We have [1] pleaded that there is no country in the world which would benefit more than our own by the provision of comprehensive electric tramway systems, or that stands more in need of them to relieve overcrowding, yet their introduction has been slow and halting, and carried out in the face of bitter opposition. Instead of lending a helping

[1] See particularly paper by Mr. Granville C. Cunningham, in the *Tramway and Railway World*, December, 1889.

hand, governing bodies seem to have thought they were doing the public a service by narrowing enterprise down to the scantiest possible outlets, and in some cases by establishing an effective blockade against it.

Twenty-six years elapsed—near upon a generation—and it was not until 1895 that the repose of the Board of Trade was disturbed—a body curiously constituted and still more curiously named—and it was found that something really must be done. A Commission was then appointed to consider the question of Tramways and Light Railways, and as a result of their report the Light Railways Act was passed in 1896, only four years ago. But this was only a tentative provision, it expires this year, and unless some measure of enfranchisement is passed, we shall be thrown back upon the Act of 1870, which remains effective upon the Statute Book.

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Until after the Act of 1888 we could do practically

nothing in the way of establishing electrical supply undertakings.

Circumstances were more favourable in America and Germany during those six valuable years, and, encouraged by the home demand, which is an essential condition of enterprise abroad, the manufacturing trades of those countries laid the foundations of their great export business in electrical plant and accessories, the consequences of which we are feeling to-day.

America and Germany now hold the great bulk of the export trade of this character, not only to the countries of Europe, and to South America where this country has heavy financial interests, but also to our own Colonies and the United Kingdom itself.

You will remember that the whole of the steam engines, dynamos, electric lifts, etc., for the Central London Railway, were supplied from America, and many other examples will occur to you.

As I have said, the legislation was in effect made to match the fact that in 1882 it was necessary to put down at least one generating station for each town, and the conception of the situation by many local authorities is shown by their persistent endeavours to wall themselves in, so to speak, against the improvements by means of which the area of economic supply has vastly outgrown such limits.

The Acts of 1882–88 and their administration have proved entirely congenial to the narrow exclusiveness of these bodies, who are endeavouring even now in their opposition to the Power Bills, to insure themselves against the developments of science and a cheap supply rather than impair the prospect of their being able to have an isolated municipal plant all to themselves some day or other.

The statistics available afford us the following figures :—

	Electricity Works in operation.		Undertakings for which Orders have been obtained, but Works not yet carried out.	
	Local Authority.	Company.	Local Authority.	Company.
1901	130	68	212	55

Of the fifty-five undertakings which have not yet been carried out by companies, only three of the Provisional Orders (not taken by transfer from the local authority) are two years old yet, and thirty-two of the remainder only date from last session. Many of the works are now in course of construction, and very few are being hung up in any way that I am aware of.

Of the 212 Orders not yet carried out by local authorities, the works in eighty-nine cases are, I believe, in course of construction or have been more or less decided upon, leaving a balance undecided of no less than 123.

Under a Provisional Order, the time within which a supply should be available is two years from the date of the Order, but of the 212 towns referred to a large proportion have exceeded that period, some of the dates tailing back so far as 1891, 1892, and 1893.

The figures do not really show the full extent to which business is retarded, because no one has tabulated the local authorities who not only have not applied for a Provisional Order, but of whom it is known that they would have blocked any application; but the state of affairs is sufficiently shown by the fact that throughout the whole of the United Kingdom electricity supply under the Acts is only available to the public in some 250 districts.

Now we know that the consumer can procure his electrical energy on a more favourable basis for all concerned from an undertaking dealing with a comprehensive area and varied classes of demand, than he can get it from a relatively small local station. This being the case, it may be supposed that it could only be a question of time when the obstacles, obstinate though they have been, to the cheap supply and to a large extension of the industry must give way somewhere.

The first break in the clouds was observed in 1898, when a Joint Select Committee of the two Houses was appointed (at the instance of the Lords) to consider and report upon a reference in regard to "Electrical Energy—Generating Stations and Supply."

Time does not serve to detail the circumstances which led up to the appointment of this Committee, to describe the Bills then pending in Parliament in which it was proposed to give effect to the developments of electrical science,

nor can I read you the full terms of the reference or of the report,[1] but I extract the following paragraphs from the latter :—

"Where sufficient public advantage is shown, powers may be given for the supply of electrical energy over an area including districts of numerous local authorities, and involving plant of exceptional dimensions and high voltage. The Committee further think that undertakings of this character may properly be authorised on conditions differing in some respects from those imposed by and under the existing Acts.

"The Committee consider that the provisions of the Electric Lighting Act, 1888, which require the consent of the local authority as a condition precedent to the granting of a Provisional Order, should be amended. In their opinion the local authority should be entitled to be heard before the Board of Trade, but should not have, so to speak, a provisional veto, only to be dispensed with in special cases by the Board of Trade."

It was the feeling of electrical engineers that the report was too moderate considering the attitude maintained by the local authorities and their notorious misuse of the powers conferred upon them by the Acts, but this feeling is turning to one of dismay at finding that during the two or three years which have ensued nothing whatever has been done to carry out the recommendation last mentioned—which is a full justification of much that I have urged—and that their exertions continue to be very largely wasted.

It might be gathered from the continued lamentations of the press that the electrical engineers of this country were likely to be put upon their defence, and this might indeed be a consistent involution of the legislation which has already tried us very severely in another sense, but it cannot

[1] In the House of Commons, July, 1898, Mr. Ritchie, replying to Mr. Kimber, said that the report of the Joint Committee would be carefully considered by the Board of Trade, but legislation would be required to give effect to some of the Committee's recommendations, and he was afraid that the prospect of passing a Bill through that session was very small. The prospect must have been small indeed, for the process of official consideration has extended not only over 1898, but also beyond 1899 and 1900.

be said that we have been slow to act upon any measure of encouragement available to us. This was true of the Act of 1888, so far as its provisions would allow, and there has been absolutely no hesitation or delay in turning to practical account the paragraph in the report from which I have just read, with reference to the supply of electrical energy over extensive areas, by means of plant of exceptional dimensions and high voltage. I have referred to the Bills pending in Parliament at the time of the report, and we must acknowledge the valuable pioneer work of some of our members in connection with them.

The Bill which affected our prospects most strongly, although it did not pass, was promoted by the General Power Distributing Company in 1898–99, and was familiarly known as the Warsop scheme, the project being to distribute electrical energy over an area comprised within a radius of 26 miles from Warsop in Nottinghamshire. This district includes such populous centres as Sheffield, Rotherham, Nottingham, Lincoln, Doncaster, Derby, and Chesterfield. The powers sought were to lay trunk mains throughout the area, to give a supply of electrical energy except where the local authority was itself empowered to supply under an order or Act and agreed to take a supply in bulk from the Company on arbitration terms. To supply direct in all cases to consumers taking 10,000 units per annum and upwards. The conditions in regard to district, etc., were favourable, and large quantities of coal slack were available at 2s. per ton in the neighbourhood of the proposed power-station. The Bill, as we know, did not then pass, but the powers which it sought to obtain have a considerable interest from the point of view of to-day, as in varying degrees they are reflected in the four Power Bills which were passed last session.

Before summarising the considerations relating to the supply of electrical energy over extensive areas, it will be convenient to follow the course of events. Public opinion became gradually informed on the subject, and it is to be hoped a little moved at the sense of national backwardness, and in the session of 1900 four Electric Power Bills, each for supply over important English areas, passed through Parliament. These were :—

THE COUNTY OF DURHAM ELECTRIC POWER SUPPLY.—This area, about 250 square miles in extent, comprises the main portion of the Durham coal-fields and one of the leading manufacturing and shipbuilding districts of the north-east coast. Provisional Orders had been obtained authorising the retail supply to consumers in the chief towns, viz., Gateshead, Jarrow, and Durham City. The British Electric Traction Company had undertaken an extensive system of electric tramways in Gateshead and district, and have since obtained powers for lines in the Jarrow and Durham City districts. The Power Act authorises the laying of trunk mains throughout the area, and the supply of electrical energy in bulk to undertakers authorised to supply, and also to undertakers authorised to use it for prescribed purposes.

Thus the supply may be given at once for general use in Gateshead, Jarrow, and Durham City, and for electric tramways and light railways in Gateshead, Jarrow, and other parts of the county.

The first portion of the main power-station on the river Tyne at Gateshead is rapidly approaching completion, and will be available this spring for a comprehensive system of supply which is being prepared in readiness for it.

THE NORTH METROPOLITAN ELECTRIC POWER SUPPLY.—This area, about 325 square miles, includes the great suburbs to the north of London, from Tottenham on the east to Harrow on the west, and the growing manufacturing districts along the river Lea. It covers the area within which the extensive North Metropolitan electric light railway has been carried through by interests friendly to those of the Act. The provisions and general considerations are the same as in the County of Durham Bill, and the same general policy was followed.

THE LANCASHIRE ELECTRIC POWER.—This Act takes in the whole of Lancashire south of the river Ribble (except Manchester, Salford, Bootle, and Stockport), an area of about 1,000 square miles. The district may appear somewhat large, but a great part of it is undoubtedly very suitable, since it comprises a large number of collieries, engineering works, cotton mills, and a variety of other industries. The Act contains powers to lay trunk mains throughout the area, and to furnish electrical energy in

bulk to undertakers authorised to supply, the promoters having relied upon the cheapness of production at large generating stations as sufficient to secure holders of Electric Lighting Provisional Orders as customers for bulk supply.

THE SOUTH WALES ELECTRIC POWER DISTRIBUTION.—This includes the whole of the County of Glamorgan and extends into Monmouth as far as the river Usk (also including Newport), an area of about 1,050 square miles. The principal towns are Cardiff, Swansea, Newport, Barry, Merthyr, Pontypridd, and Neath, and the district thus comprises the great colliery, shipping, and manufacturing districts of South Wales. The provisions of this Act are similar to those of the Lancashire Act, with one important difference. The South Wales Company were given powers to supply direct to *any* person for power purposes, and for lighting any premises on some part of which the power is utilised, provided only that in a local area where an Electric Lighting Provisional Order exists, the consent of the authorised distributor in such area is first obtained. If such consent is withheld the Board of Trade may dispense with it, if in the opinion of that body the authorised distributor under the Provisional Order is not willing and in a position to give the requisite supply to the power-user upon reasonable terms and within a reasonable time.

All these Acts contain a sliding-scale clause as regards prices and dividends, also powers for the revision of the scale every ten years by the Board of Trade, 8 per cent. being taken as the normal maximum dividend. The general clauses follow pretty closely the usual electric supply practice; for details reference should be made to the Acts themselves.

There are a few examples of groups of Provisional Orders having been obtained for adjoining districts by arduous negociations extending over several sessions. These undertakings typify many of the difficulties with which electrical engineers have had to contend, but they are not more fully referred to here as the form of procedure was not by Power Bill. There is, however, an important Northumbrian undertaking dealing with the north bank of the Tyne from Newcastle to North Shields (excluding the latter) with part of the hinterland,

which belongs to both classes and should not be omitted from the list, especially as it has been one of the first to get to work.

The main purpose of the Power Acts is to keep the number of power-stations within economical limits, and by the selection of suitable sites and the equipment of works of considerable magnitude to enable electrical energy to be transmitted in such a manner that the retail price to the consumer will be reduced to a figure which will compare with, and in many cases be far lower than, that of any other form of power, whether gas, steam, oil, or other agent.

The enormous development of electricity in the United States and Canada and on the Continent of Europe, and the numerous great electrical power distributions over large areas, in those countries are in themselves practical evidence in favour of the principles we are advocating. It cannot be urged that the requirements of this country, so far as trade and cheap production are concerned, are different to those obtaining in the countries mentioned.

The absence of undertakings of the kind in the United Kingdom has not been on account of any difficulty or impossibility on the engineering side, or from lack of suitable conditions. We have few large water powers it is true, but there is an equally good source of power available, and coal in this country can replace, on favourable terms, the water power available elsewhere for the generation of electrical energy. Moreover, even in those parts of the country where coal is more expensive than in the coal districts themselves, relatively cheap electricity may be available if it is generated in sufficient quantity at large power-stations, and the supply from such stations is distributed over a suitable area. Capital charges, management, rent, rates, and taxes usually form a larger proportion of power-station costs than fuel, but the greater the importance we have to attach to the fuel item, the more necessary it is to adopt the most comprehensive methods and to concentrate and economise its use.

Under the Electric Lighting Acts, and the conditions heretofore existing, the scarcity of the electricity supply in this country has been due to the high cost of production. Even in the more developed areas the cost has been too

high as a general rule to admit of its being freely used by the consumer on terms more advantageous than those upon which he can employ steam or gas for industrial purposes, or gas or oil for domestic service.

Statistics have shown us that the average cost of production and supply to consumers becomes lower as the output of the power-station increases, but the difference between stations supplying one million and four million units per annum is less, and not in proportion to that obtaining between smaller stations with much less difference of output. Without an increasing "diversity factor" this difference would tend to disappear as stations increased in size.

A good "diversity factor" can only be achieved by combining with electric lighting the supply of energy for as many and as various other purposes as possible, and, so far as lighting is concerned, the supply to every class of consumer. As the area of supply is extended, the "diversity factor" tends to improve owing to the difference in the incidence of the demand in different districts.

I shall not attempt to follow the more technical aspects of the subject just now, as they afford scope for many papers, and certainly for more discussion than you can give to them this evening; but it may be well to summarise the points for and against the old system and the new, *i.e.*, the supply from small local stations and the supply from main power-stations:—

Supply over comprehensive areas from main power-stations in selected positions.

ADVANTAGES:

1. Comparatively large field for development.

2. High load-factor obtainable, all the plant being used to the best advantage.

3. Cost of fuel and handling can be reduced to a minimum, as the power-station can be located where fuel is cheapest, fuel handling most economical, and water is available for condensing.

4. Low running costs, management expenses and maintenance per unit sold, as the result of a very large and regular output.

5. The low cost of plant per kilowatt installed, and the increased economy in running with very large sets.

6. Low rents, rates and taxes ; the difference between town and country.

7. Economical provisions for extensions to plant and buildings.

8. Low costs and charges for electrical energy for all purposes possible in consequence of above advantages.

9. Removal of the power-station with its chimneys, etc., outside the residential district.

DISADVANTAGES from point of view of Local Authority:

1. The transmission mains must pass through their area whether supply be taken or not.

2. Sentimental preference for complete independent plant of their own.

Supply in small local areas from separate stations.

ADVANTAGES:

DISADVANTAGES:

1. Small field for development.

2. Relatively low load-factor.

3. Cost of fuel, handling it, and water supply depend on immediate local conditions, favourable or unfavourable.

4. High running costs, management expenses, and maintenance, the costs per unit sold being generally higher the smaller the station.

5. High relative cost of machinery per kilowatt installed, and lower economy in running.

6. Rents, rates and taxes relatively higher.

7. The extension of buildings is frequently very expensive, owing to disturbance and other difficulties incidental to town sites.

8. High charges for electrical energy for all purposes as result of these disadvantages.

The story of George Stephenson and the cow on the line has come down to us as typical of the prejudice and the ignorance with which[1] railways had to contend in their early days; and so, too, when the early history of the electrical industry comes to be written, the part played by the local authorities in their strenuous opposition to the Power Bills will be a record of reproach to them.

For the purposes of this opposition there was a conference of local authorities in Manchester in January, and a meeting of the Association of Municipal Corporations in May. The object of the first meeting was to prevent the second reading, and that of the second to influence the decision of the Parliamentary Committee.

The methods adopted by those who endeavoured to wreck the Power Bills were strongly condemned in the course of the second reading[2] debate, and the President of the Board of Trade found it necessary to repudiate a garbled report which had been circulated as to his remarks upon the Bill for the Warsop project in the previous session.

Every one interested in the welfare of the industry should read and think over that debate. True, the Bills were read a second time and committed, but what a curious light is thrown by the discussion upon the difficulties with which we have to contend!

Perhaps there is time to mention two examples. Mr. Ritchie said, ". . . I hope the House will give its attention to the very important considerations in this case before they decide to reject on Second Reading a Bill that is fraught with so many possibilities. It is true, I think, that the electrical enterprise of this country is in an exceedingly backward condition; it is inferior with regard to light, and certainly with regard to the conveyance of power, to many European countries, and it is greatly inferior to North America and Canada. It may almost be said that there are

[1] In 1801 we had no railways in the sense we now use the term. To-day the railways of the United Kingdom extend to about 22,000 miles of line, constructed at a cost of about 1,300 millions of pounds. The annual gross receipts now exceed 100 millions, and of the expenditure, which amounts to over 60 millions, fully one-half is distributed in wages to over half a million employés.

[2] See *Parliamentary Debates*, No. 2, vol. 79 (page 1,374 and following), published by Wyman and Sons, Limited, Fetter Lane. Price, 1s. 3d.

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villages in North America which are in possession of advantages in connection with electricity which some of our largest towns do not possess. It cannot be doubted that there is a great demand for something to be done. At present electric light matters are governed largely by the legislation of 1882, and it has been said that this Bill is largely in opposition to many of the enactments in the Act of 1882. If no other charge or argument could be brought against this proposal, the argument of the opponents to this Bill would indeed be weak. It must be remembered that it was the Act of 1882 which more than anything else had delayed and hampered the development of electrical supply, and in so far as this Bill departs from that Act, I think its departure is amply justified by the condition of things at present existing in the electrical world."

Here we have a member of one of the strongest Governments of modern times, the Minister entrusted with legislation affecting the trades of the country, who has realised the extent and cause of our backward condition in relation to a great industry, and ingenuously confessing that during five long years of office one of the main causes of the trouble has remained effective upon the Statute Book.

Sir William Harcourt said, ". . . I do not altogether share my hon.[1] friend's objections to great enterprises being carried on through private sources. That was a question which occupied fifty or sixty years ago the attention of this country, and that was at the time of the commencement of the great railway interest. That question was decided by the wisdom of the great statesman Sir Robert Peel. We know that Sir Robert Peel was much attacked at that time for throwing the railway enterprise of this country into private hands, and not adopting the system so largely followed on the Continent. I look forward to this question of electricity and electric supply as the great question of the future, and it is from that point of view that I wish to refer to the subject. If this company is prepared upon proper conditions to supply electricity to any part of the country, I am not opposed to that. No man can say to-day what part electricity may not play in the industry of the country, and that is a point which the House of Commons should keep

[1] Mr. Broadhurst.

in view. But what are the conditions which ought to be imposed? What was the policy which was pursued with regard to the railway companies? Parliament did not leave it altogether to particular promoters of Bills; Parliament did not leave it to the discretion of individual committees. They placed the whole of that great enterprise, upon which more than a thousand millions of private money has been expended, greatly to the benefit of the country—a sum larger than the National Debt, and now paying interest at least of 4 per cent., and one of the greatest investments for the savings of the country—under general legislation. I think that a model which we ought to follow in this instance. But what was the method which Parliament in those days adopted in dealing with the railways? They did not allow particular promoters to take their chance in individual committees. They placed the whole of that great enterprise, as I have said, under general legislation. . . ."

This statement of Sir William Harcourt goes to justify the charge that the Legislature has neglected an industry the importance of which he describes in suitable terms, and it also leads us to the economic aspect of the question. Comparisons have been drawn between the benefits first derived by every class of our community from the applications of steam power and of railways, and those which have accrued to other nations in larger measure than to ourselves from the uses of electrical energy. The United Kingdom itself has not yet lost any material part of its natural advantages for the manufacture of engineering material, or of scope for their employment. In what way has destructive legislation acted so as to place us in the position of inferiority we are reproached with to-day?

It has, among other things, tended to destroy cumulative investment effect. Savings out of the profits of a business tend to go back, as an additional investment into that business or some department of trade allied with it. Part of the profits derived from railway enterprise undoubtedly went in again, and attracting new capital to it, provided means for building new lines and for equipping rolling mills, foundries, engine works, and other undertakings which have provided employment for thousands of our fellow-countrymen. No influence has done so much

during the past hundred years to stimulate enterprise, to encourage commerce, and to develop the resources of any country.

In our own time legislation has not only deprived the great mass of the people of the direct benefits of electrical science, but it has made much of what little has been done indistinguishable to the investor from local government loans for drainage, refuse destructors, slaughter-houses, and other purposes most necessary in themselves, but somewhat in the back-yard of civilisation.

It may be replied that Sunderland, for instance, has just declared a profit out of its municipal tramways, but what advantage has this been to any one? The fares have been substantially the same as would have been charged by private enterprise or the amount would not have been earned. The local rates we may be sure will not go down, and if they are a trifle lower than they otherwise would have been, those to benefit most will be the railway company and other large ratepayers who have contributed least to the tramway revenue.

The banks, insurance companies, and such institutions which provide much of the local government loan capital will get their 3½ per cent., and part of it may be re-invested in colourless loans elsewhere, but of that great encouraging influence towards the growth of healthy industry which I have imperfectly described as the cumulative investment effect, there will be little or nothing.

And the money for the purpose has been deflected elsewhere. The subject is a complicated one, and it may not be in place to follow it here, but it is a significant fact that *exclusive* of foreign loans the yearly increase of capital from this country invested abroad averages at present about £30,000,000. One tendency of this has been to set more people to work abroad instead of at home, and to increase the competition against home industries.

In the interests of which class of the community the enactments I have referred to were passed and have been administered by the various authorities, it is difficult to say. They have not benefited the general public, the complaint made on their behalf is that they are debarred from the advantages of electricity; and least of all have they benefited the working man, who finds that while the electric

light and comprehensive electric tramways are not for him, hundreds of thousands of pounds' worth of foreign-made plant and accessories are landed on our shores.

The working classes have suffered in another and, perhaps, a more serious way from the division of the country under innumerable local authorities endowed with powers such as I have described. The more or less arbitrary boundaries of these authorities derive in some cases from the middle ages, they are not and cannot be adapted to one and all the various means by which science and enterprise can be brought to the aid of the general community, and it can be shown that in practice the system tends to aggravate some of the grievous social and industrial problems of our own times.

These authorities number among them men of great ability and benevolence, but their collective action is frequently controlled by traders, property owners, and others who act upon the view that the best interests of their several districts lie in the direction of increase of rateable value and of population. Add to this a large official class alive to the advantage of increasing the importance of its own environment, and there need be little wonder that each district shows a tendency to "cuddle up" all it can attract, and that there should be grave reason for our being urged "to get rid of that which is really a scandal to our civilisation, the suffering which many of the working classes have to undergo in order to obtain even the most moderate, the most pitiable accommodation."

There may be many fibres to the scandal of the housing of the poor, but the conditions most favourable to its growth are to be found in our system of local government and its administration.

The future of the electrical profession is so interwoven with social questions that we cannot escape their consideration. Mr. Balfour has said, "I believe that electrical traction is going to play a far larger part in the solution of this difficulty"—the housing of the working classes—"than any of the strange schemes I have analysed"; Mr. Lough that "It has been agreed by everybody that the chief means of improving housing accommodation is to spread out the city and destroy congestion, and it is agreed that there is no way of doing this effectually except by providing better facilities for traffic."

No one can question the advantages of improved traffic facilities, but if the direction morning and evening is to and from a congested trade centre the problem is only half solved. It is to electric power distribution on a sufficiently comprehensive scale to adapt the country districts to manufacturing purposes, in company with inter-urban connection by means of electric traction, that we must look for the greatest agency in ameliorating the conditions of the working classes in all their surroundings.

It can scarcely be asked what has all this to do with the Institution of Electrical Engineers, for we have seen that the community is conscious of the backwardness of our work, and faced by social phenomena such as those to which I have referred, we are called upon to perform our part in counteracting them. Electrical science is ripe for the occasion, and it therefore appears to be our duty and to our interest to convince the Legislature as to the means it should take to enable us to carry on the services assigned to us.

As some technical objection might possibly be raised to any action we may take in this direction, we shall find, on consulting the Memorandum and Articles of Association, which describe the scope and general organisation of the Institution, that (among allied objects) it was established "*To promote the general advancement of Electrical and Telegraphic Science and its applications, . . .*" (*Sect.* 3 *B*), and "*To do all such other lawful things as are incidental or conducive to the attainment of the above objects*" (*Sect.* 3 *D*).

Article 53 says that "*It shall be the duty of the Council to adopt all due means for the advancement of the Institution; to provide for properly conducting its business in all cases of emergency . . .*"; and a preceding *Article* 49 provides that " . . . *The Council may appoint Committees chosen from their own body, and Committees for special purposes consisting of Members of Council and Members, Associate Members, or Associates of the Institution and others, with such powers as the Council may prescribe.*"

Thus the terms of our Constitution not only authorise action being taken, but they also appear to intimate the course to be followed in dealing with any obstacles with which we may have to contend, and I trust that the

discussion will give the Council an indication as to the desirability of appointing a special committee, as provided by *Article* 49, to consider what steps should be taken to remove the restrictions upon us, some of the effects of which I have endeavoured to describe.

The President.

The PRESIDENT: We have received a telegram from Mr. Garcke, Mr. Stephen Sellon, and Mr. Morse, stating that they have been unavoidably detained in the country. The following letter has been received from Mr. Vesey-Knox:—

Mr. Vesey-Knox.

Mr. VESEY-KNOX (*communicated*): I am sorry not to be able to avail myself of your kind invitation to hear Mr. Madgen's paper, which I have read with interest. If I might venture on a word of criticism it would be this:—The question seems to me to be altogether one of price. In the case of tramways other considerations operate; but, so far as mere electrical supply is concerned, Parliament has now in principle decided that any company offering economic advantages shall be given an opportunity of supply, with due regard for vested interests. If the companies can, in fact, supply cheaply, they have now a wide field open to them. They can practically force local authorities whose Orders are hung up to take current by offering it at a cheap price and without capital expenditure. The real reason why many people who are not prejudiced in favour of socialistic experiment have supported municipalisation of electric light undertakings is that so many of the companies have charged such high prices for current. This has been a short-sighted policy, even from the point of view of the particular companies themselves, as, except in districts where people will have the best light at any price, the cost of supplying at a high price is much greater than that of supplying at a low price. With high prices you may have a big district and big works very irregularly employed, and the undertaking loaded by a cost in distribution mains out of all proportion to the number of consumers. But even more unfortunate has been the general effect upon private enterprise, by depriving promoters of the really practical argument against the obstruction of the less enlightened local authorities. It is in some ways a pity that the sliding scale clauses were not applied to electric lighting undertakings instead of the clauses giving the Board of Trade power to alter the maximum price after seven years (s. 31 of Electric Lighting (Clauses) Act 1899). The case of Cork, which was not a favourable field, is a remarkable proof of what low prices may do. There a supply at an average price of under 3d. was profitable in the first year. At 6d. probably no profit would have been made for five years.

The sliding scale has now been applied in the case of the Power Bills, and it is to be hoped that this will have the natural commercial effect upon the undertakings. I do not believe the public are disposed to look unfavourably upon even "monopolies" if they derive therefrom, in comparison with other districts, evident and palpable facilities; and, after all, it is the public who, in the long run, control the local authorities.

Mr. Sellon.

Mr. R. PERCY SELLON: So much of the time of our Institution is taken up in the discussion of subjects of a purely scientific character, that it is seldom—and, for my part, I think too seldom—that we have before us a paper of the kind which Mr. Madgen has read, dealing with Electrical Engineering questions from their political and industrial aspects. This paper relates to principles rather than to details, and it goes down to the very foundation of the issues upon which the progress or backwardness of electrical engineering in this country depends, and upon which the great majority of the members of this Institution depend for their livelihood. In my opinion, therefore, the paper which Mr. Madgen has brought forward is one of great importance; and I think its interest falls under two heads, namely, the technical problems attaching to these large power-distribution schemes, and the consideration of the matter from the collectivist or political point of view.

With regard to the intrinsic merits of these schemes, Mr. Madgen has dealt with them at considerable length, and on page 490 he has stated fully, and, I think, fairly, the arguments for and against such power schemes, which depend upon this root question: Is it in the interests of the public as a whole that there should be a few large stations distributing over large areas, in preference to a larger number of small stations distributing over smaller areas? There are problems of generation and distribution which I do not propose to deal with. I will only say, in general terms, that it appears to me that the spirit of the time, which makes for the consolidation of industries and trades in all fields, points by analogy to the economic merits of large power-distributing schemes as compared with small stations located in each town. It seems to me that it is a reproach to our Institution that we should be palavering and debating over the question whether or not these schemes are possible, while countries which were far behind us in industrial progress half a century ago have already proved them to be desirable by such stations as those at Niagara and Messina, Rheinfelden in Germany, and Chevres in Switzerland, and Fiume in Italy. Why is it that we are at present in this backward state? I think the answer is, as Mr. Madgen has pointed out, because the progress of the electrical industry in this country has not been determined by its merits, but by political considerations. It is a misfortune for the electrical industry that its birth and its growth, up to the present, have been coincident with the birth and growth of the "municipalising" idea. Hence it has come about that our industry has become the plaything of politicians and of those who are anxious to municipalise all public supply in the interests of the democracy. There is no doubt, to my mind, that that is the real explanation of the fact that in this country we are quite without large distributing schemes, whilst abroad they are already in existence. Note the fact that this difficulty has arisen at every stage of the electrical industry. In the case of electric lighting, the Electric Lighting Acts retarded growth; then the Electric Tramways Act of 1870 was only with great difficulty amended by the passage of the Light Railways Acts, which late in time have given Electric Tramways a possibility of existence; and now these electric power schemes have been made the battle-ground of the two contending

parties—those in favour of municipalisation and those who advocate leaving the development of new industries in the hands of private enterprise. It is true that the Legislature has at last made a tardy recognition of its errors of judgment in the past, and by the passage of these Bills has recognised that the public interest does point to infant industries in their early stages being placed in the hands of private effort. But, I would like to point out that help has come almost too late. Investors, who, after all, supply the sinews by which these schemes are rendered possible, have grown to look askance at electrical enterprise. Parliament has bandied about electrical enterprise, has pursued such a vague policy, has imposed so many regulations upon electrical schemes, and local authorities have been so largely pandered to, that it is very small wonder that the investor can now with the very greatest difficulty be persuaded to believe that there is for him commercial advantage in embarking upon electrical enterprise. We often hear it said by politicians and others that we shall "muddle through somehow." Well, we may mismanage a war, we may have mismanaged many questions in the past, and the country has "muddled through" because those wars and those enterprises were conducted under conditions where this country had either the superior power of the purse behind it, or armaments, or some factor, which enabled it in the end to overwhelm its enemies. But in electrical enterprise that is not the case. Our great rivals in America, in Germany, in Switzerland, have all the advantages—material, financial, and technical—that we possess; and therefore the theory of leaving these things to "muddle themselves out," rather than handling them by concerted and associated action, is one that must be dismissed with regard to the electrical industry. Mr. Sellon.

What is the cure for this state of things? The roots of the trouble lie so deep in political and other considerations that we cannot in this Institution survey the whole field over which they are spread. The practical question for us is, What can this Institution do in its own sphere to add its quota towards the removal of the disabilities from which the industry is suffering? The answer to that lies in the suggestion that Mr. Madgen has thrown out. I know that we, as an Institution, are rightly on our guard against taking any action which may appear to benefit one class of our members at the expense of any other class. But where the interests of electrical engineering as a whole are at stake, I contend that this Institution should take a more active part in the support of those associations and individuals who are engaged in the struggle to better the conditions under which we work. I believe that that can be done. We know that there are legislative questions now before the Board of Trade and other State Departments which are menacing the development of the electric traction industry, of these power-distribution schemes, and of electric lighting. I hope that the reception which members will give to this paper will strengthen the hands of the Council by enabling it to feel that the whole body of members is behind it in lending the weight and the authority of this Institution to the support of remedial measures calculated to remove the disabilities under which our industry is labouring.

Mr. J. S. RAWORTH: The very important paper which Mr. Madgen Mr. Raworth.

Mr. Raworth.

has brought before us covers such an enormous number of side issues that I shall confine myself entirely to a consideration of two questions, Are we behind the position we ought to have achieved? and, What are the causes that have brought about this lagging? In a meeting like this, which generally devotes itself to scientific questions, there must be many present who, as it were, never get away from their calculations, who fail to take a broad view of the industry at large. They see that everybody around them is busy, and therefore they think that the industry is in the flourishing position in which it ought to be.

Now, let me compare our position in electric light engineering, not with the position in America and on the Continent, where the conditions may be different, but with that of the gas companies, which draw their customers from the same class of people as that which furnishes ours. Our position at the present moment is this (I am now comparing the figures of 1898, which are the only figures available for comparison): The total revenue of all electric light and electric power companies in the United Kingdom of Great Britain and Ireland amounts to £1,606,000 per annum. But it is astonishing to note that the *increase* in the revenue of the gas companies in the two years from 1896 to 1898 exceeded the sum total of all our revenue; that is to say, it increased from 19 millions to 21 millions, making a total increase in revenue of £1,611,000. I ask you to realise that in the face of all the electric lighting stations which have been started throughout England, the gas companies have been able to add one million and a half pounds to their revenue. Further, the profit which the three large gas companies in London derive from the supply of gas is £1,655,000 a year, that profit being greater than the total revenue of the electric lighting companies in Great Britain and Ireland. With those figures before them, who could say that our industry has not been choked? We have been working at it as hard as we could in supplying electric light for twenty years, and yet we have not gained more than £1,606,000. Some may say that we have been putting down stations as fast as possible. The result is, we have 198 stations working to-day, and the gas companies have 661, showing that they are still a long way ahead in numbers as well as in the breadth of their operations and their power of collecting money. Now, I have no great antipathy to the idea of municipal trading; I do not object to the municipality trading, because they bring competition into our field of operations; and I do not object to the ratepayers taking the risk upon their shoulders if they are content to do it. My objection to municipal trading is based upon the ground, which I explained at great length two years ago, that they do not manage the business as well as the companies do. I say that, in that great industry of gas, which was based upon the principle of perfect equality between the company and the municipality, there was no advantage to the municipality which the company did not also have, and the companies beat the corporations entirely, and supplied a better article at a lower price. It was only when we came to tramways and electric lighting that the new principle was introduced of giving an advantage to the corporation as against the company. And I contend

that, if those advantages on behalf of the corporations were taken away, we should no longer have cause for fear, because the municipalities would not choose to go into the field where there was free trade. It is the special provisions of those two or three Acts of Parliament that bring about the great mischief from which we suffer at present. As General Webber might have told you had he been here, between 1882 and 1888 it was impossible for any electric lighting stations to be started, because the capital could not be got. Then the period for purchase was extended to forty-two years, and so we now get the capital, but only with very great difficulty. Further, the difficulty is increased by the violent opposition of corporations to the granting of an Order on fair terms. If it be urged that there are a great number of gentlemen ready to come into the business, to put their money into it, and take the risk of electric supply, it must further be considered what a large amount of capital they have to spend in overcoming the opposition of local authorities. It was said by Mr. Vesey-Knox that if people are prepared to supply at a cheap rate they can get permission to supply over a very large district. Let them try to do it, and they will find they have to spend weeks in the rooms of the House of Commons arguing the point *ad nauseam* with people who only want to keep them out; and an enormous sum of money is spent often without any success or reward at all. Those are the obstacles put in our way by the Legislature, and if those were removed and we were put on equal terms, we should have no more trouble with municipalities. Mr. Raworth.

Mr. SWINTON: I agree with Mr. Sellon, that this is a subject of very great importance; it is a pity that we do not more often have discussions upon subjects of this description here. It is true that this is a scientific Institution, but it is no use having discussions upon, for instance, dielectric losses in cables, if we have no cables in which dielectric loss can occur. Mr. Madgen has stated in his paper the chief reasons for the backwardness of the electrical industry in this country. Up to a very short time ago—I do not think it is so now—if such reasons were adduced for the backwardness of this country, there was always a certain class of persons who denied that those were the real reasons, averring that the true reason was the speculation that took place in electric businesses about the year 1882. I do not think that the British investor has such a long memory that it takes him back to the year 1882; the usual cycle of memory of the ordinary Stock Exchange investor is very much shorter than that. There is no doubt that the primary reasons for our backwardness in electrical matters in this country are traceable to the Tramway Acts and the two Electric Lighting Acts, and, I must add, to the administration of those Acts by the Board of Trade. Mr. Madgen has stated in his paper that the Board of Trade is curiously named, and somewhat curiously constituted. I have personally been at some pains recently to inquire into the constitution of the Board of Trade, and I have had great difficulty in finding out anything about it. In any ordinary book of reference, under the heading of "Board of Trade," there are mentioned the President, the Secretary, and various sub-secretaries, but there is no reference to any Board at all. I have pursued my investigations, and find that the Board Mr. Swinton

Mr. Swinton. of Trade has been in existence for some centuries, that it has led a very chequered career, having been several times entirely suppressed, but that, as at present constituted, it consists of a Committee of the Privy Council, formed of various high officers of State, and includes, *ex officio*, the Archbishop of Canterbury! I need scarcely say that the Board of Trade appears to be but seldom called together, and in fact exists merely in name. Now, I think that that really goes to some extent to the root of the matter. At one period in the history of the country the Board really existed, and probably was of some considerable importance; for I find that Oliver Cromwell, who did much to increase the power of this country both abroad and at home, appointed on the Board of Trade twenty merchants of the City of London. If something of that kind could now be done towards constituting a Board of Trade which would be truly representative of the industries of this country, and which would guide the President and Secretaries, it would be a very good thing.

To pass to another question: it must be evident to any one who thinks about the matter that putting any new industry into the hands of bodies like municipalities must necessarily lead to that particular business proceeding very slowly. Municipalities employ the ratepayers' money. They must not speculate; they can only take up businesses the success of which is absolutely assured. At the beginning of all new enterprises there is necessarily a speculative period, and, if enterprises of that description are entrusted to municipalities, they must necessarily wait until other people have shown the way. That is what has happened in this country, and it is, I think, one of the objections that goes to the root of all municipalisation. Private enterprise is the only legitimate way of trying new things. Even if, as I do not believe is the case, the result is that, in any particular town the municipality can supply electric energy more cheaply than can private enterprise, that may be to the advantage of the particular inhabitants, but owing to the fact that it throws things back it cannot be to the advantage of the country. If, in the early days of railways, this country had been content to wait until other countries had made railways, I have no doubt that ours would have been constructed very much more economically than they were, and very likely we should now be able to travel more cheaply. But the country would have been vastly the poorer. This country was the pioneer in railways; it made railways all over the Continent, and I am quite convinced that the amount of profit that was made and the capital value of all that advantage, has been very much greater than would pay ten times over any excess in fares that perhaps we pay to-day for travelling.

Previous speakers have alluded to the fact that, at the present moment, it is not easy to raise money for electrical industries. Again, I think the reason is largely the fact that the greater portion of the electrical business in this country is in the hands of municipalities. In nearly all our large towns, except London, the electrical business (lighting, power, and tramways—or at any rate the lighting and power) —is in the hands of municipalities. Any one wishing to raise money for some electrical undertaking in the country finds that the people

Mr. Swinton.

will not look at London; they say it is an exceptional place, and cannot be compared with their town. But, leaving London out of account, there is no place, or at most but few places, that can be pointed to where large profits are being made, because it is all in the hands of municipalities, and the municipalities do not pretend to make profits. As showing an instance of that, I may mention Newcastle, which is a fairly large town, and in which there are two private companies, both of them very prosperous. It is noteworthy that the electric supply undertakings in two other towns, Scarborough and Cambridge, are almost entirely capitalised from Newcastle—at least two-thirds of the capital comes from there—the reason being that the people in Newcastle who had put money into electric light undertakings had found it very profitable, and were ready to invest in electric enterprises elsewhere. Hence it may be argued that, supposing the electric light of Edinburgh, Glasgow, Liverpool, Manchester, and all the large towns, instead of being in the hands of municipalities was run by well managed companies, all paying their 10 or 15 per cent., there would be no difficulty in getting any amount of money for electrical enterprise. I think that one of the things required is that some body of persons representing the electrical industry should assert themselves. I have a very high opinion of Government permanent officials, but they take the line of least resistance to a large extent, and if they are entirely pushed one way they will go that way. At the present moment the pushing is nearly all done on one side, namely, the municipal side, by the Association of Municipal Corporations, and bodies of that kind; and what is wanted is that some body should push the other way, and I think that this Institution might do this to a certain extent. Of course this Institution is primarily scientific. Very likely the Institution of Civil Engineers have never done exactly what I think this Institution ought to do; but then circumstances alter cases, and exceptional circumstances require exceptional remedies.

Mr. Atherley Jones.

Mr. LL. ATHERLEY JONES, M.P.: I must confess I came here with the idea that I should simply have to perform the agreeable duty of listening to the observations of gentlemen more competent than I am to express an opinion upon the subject-matter of Mr. Madgen's paper. But perhaps there was some solicitude that, inasmuch as an attack had been made—perhaps not an unmerited attack—upon the Institution of which I am a member, it would only be a graceful act to call upon me to say a few words in its defence. I frankly admit that Parliament has been, perhaps, remiss in the efforts which it might have successfully made to encourage and develop the great electrical enterprise, whether by way of traction or whether by way of lighting, which has had such marked success in other countries, but which in this country, through causes which have been lucidly traced by Mr. Madgen, have not met with corresponding success. But we are probably all agreed that, within the last few years, at any rate, there has been a growing conception on the part of Parliament that the interests of the community can perhaps be better served by adverting to the dictates of private enterprise, rather than the narrow and somewhat insular interests of municipalities. I am far, indeed, from saying one word which would

Mr. Atherley Jones.

reflect upon our municipal government. We owe the creation of that public spirit which finds its best demonstration in private enterprise, to the encouragement of the growth of that free spirit which exists in our municipal government. But at the same time we have perhaps coddled our municipalities a little too much. We have recognised by recent legislation that the chess-board system—if I may use the expression—of local government is not that which, in certain directions, is best suited to serve the public benefit. And therefore, instead of taking some small municipality as the unit for the purpose of local government, you have ignored that small municipality, and have merged your scheme of local government in the larger unit of the county. That has been done in various matters of local government, but it has not been done in respect of electrical enterprise, be it lighting or be it traction. Therefore it is we find that one of the greatest hindrances, probably, to the development of electrical enterprise, in traction or in lighting, has been the veto which can be exercised by local authorities over the private enterpriser. That, I think, will be removed. I think that Parliament, in passing the Power Bill in the last session for the county of Durham and for a certain portion of South Wales, recognised that the will of the municipality was not to override the necessities of the public at large. Because, if I remember aright, that Bill, or one of them, met with very considerable opposition from municipal authorities; and I understand that similar Bills in this coming session of Parliament are likely to meet with similar opposition.

There is one other topic of Mr. Madgen's paper which struck me very forcibly, and that was where he advocated the desirability of developing and encouraging electrical enterprise in the interests of the huge masses of our population aggregated in labour districts. I believe, and I think that that is the opinion even of that much-abused body, the Board of Trade—whatever the Board of Trade may be—that it is desirable that facilities should be afforded, to what length perhaps it is difficult at present to say, for tramway companies and light railway companies to construct, under more favourable conditions than at present, means of transit from the centres of industry to those more distant places in which alone cheap habitation can be obtained. And if the present President of the Board of Trade devotes his attention in this session of Parliament to making successful the Light Railway Act, which is to some extent, I believe, to supersede the present Light Railway Act, and which might perhaps reasonably supersede in some respects the Tramway Act—that will lead in no small measure to the development of electrical enterprise in this country.

I will only say it has been a great pleasure to me to listen to the interesting observations which have been made. I suppose I may be permitted to say I have been able to induce the Board of Trade to receive a deputation to discuss the precise scope and direction of the new Tramway Act, and that these matters which have been dealt with so ably by Mr. Madgen will undoubtedly be laid before the Board, and I hope will bring forth good fruit.

Professor Silvanus Thompson.

Professor SILVANUS THOMPSON: We are all indebted to Mr. Madgen for having brought before us this topic, for I doubt if a more important

Professor Silvanus Thompson.

subject could have been brought before this Institution at the present time. It is really a national question—this matter of being able to supply power cheaply to our industries. And I would like to point out that there are one or two small, comparatively simple, matters, in which it is desirable that we should have our minds quite clear. It is sometimes urged against us when we advocate the establishment of these large power-stations, and when we adduce, as practical reasons why they should be encouraged, those large power-stations on the continent of Europe and in North America, that those stations are almost all without exception water-power stations. They say, "You have no waterfalls in England worth having, and you do not know anything whatever about working power-stations except those which have water as the natural source of supply." I do not admit the argument. In the first place, if there is a waterfall that is not yet taken for power purposes, that waterfall belongs to somebody, and that somebody will want his price for it so soon as it is known that the power of the waterfall is worth money. Whoever wants to take that waterfall for water-power purposes will have to pay for it; and the price which he will have to pay is that which he would have to pay to run in some other way the works which are going to be run. That is the factor which sets the price. You do not get water-power for nothing, although Nature provides you with the water falling over the precipice. We have in this country, as everybody knows, cheap coal; coal which Nature also provides free of cost, but which belongs to somebody, and which costs us money for digging up. The economic problem is not coal *v.* water-power, but how to make use of the natural source of power which we have, whether it be coal or whether it be water. The engineering may be different, but the economic problem is really precisely the same. And the dearer the power is, as Mr. Madgen has well remarked, in itself, the more there is to be gained by distributing that power as economically as possible. So that if it be true that power costs us more by being generated from coal than by being generated from water flowing over a precipice, it is all the more necessary then that we should have an economical system of transmitting it and distributing it.

Another practical point is, that we want information, and I will ask Mr. Madgen in his reply to give it. Where are there (I know of some) large stations worked by coal as distinct from large stations worked by water? I do not ask, Where are coal-stations for the purpose of sending power to a long distance? That is not the question. But, Where are there large stations economically transmitting electric current to the district round them for any purpose whatever? We want to know the figures for large coal-stations in comparison with those of the water-power stations when we have to talk to the people who are impervious to the argument that water-power cannot be got for nothing. Then another thing we want to know is, What is the proper basis for reckoning out the suitable size of unit for a big power-station? Of course I know that no one answer can be given: it depends on local conditions. But when we are told that a municipality intends to supply power as well as light, and that then because it has a station big enough for 1,000 H.P. it will therefore

Professor Silvanus Thompson.

be able to compete economically with one of those large power-schemes which has a big central-station a few miles away, we want to know, and have the facts for it, Where is the size of station at which it becomes no longer economical to make it larger, where it would pay better to put a second one up at some other convenient place on another coal-mine a few miles away? Unquestionably facts can be got at, but they have never been stated, so far as I know, in a compact, concise, or useful manner, that could be used effectively for the purpose of convincing those who do not understand what the real problem is. Is it true, for example, that when you get a station up to the size, as I have been told—I do not accept the figure—of 10,000 H.P. it does not pay to go on to make it up to 20,000 H.P., and that you had better put up a second station a little way off? You know that directly you double the station by dividing it into two at a distance apart, certain expenses are doubled, which would not be doubled if the station remained as one large station. I need not go into the details of it, but it is obvious that there must be additional expenses whenever you break ground in a new place. Is there, or is there not, a limit of size beyond which the increased output will no longer produce a cheaper output? Our municipalities up and down the country sometimes use rather curious arguments. One that I have heard used, rather effectively, against a big power-station coming into that municipality was that, seeing that they were makers of their own gas, they had a very large quantity of coke, which they sold every year, and on the sale of their coke at a cheap price they made profits, and that no power-station twenty miles away could possibly dig up fuel for itself which would be cheaper than the spare coke which they themselves produced. Of course, the obvious answer to that is that that municipality is making huge profits out of the gas that it sells; it is not selling that gas nearly as cheap as it might do, but it is taxing the community for the gas over which it holds a monopoly, and throwing away, or selling very cheaply, a waste product, that need not be in that sense a waste product. The economic unit of size for electric supply must clearly depend upon very different conditions from those which determine the economic unit of size of area supply for gas, or water, or milk, or other things. Take, for example, the case of water supply. In old days we had the parish pump, and then we had the village cistern, the village reservoir; then we had the town supply. Now look at what all the large municipalities in this country are doing in the way of providing themselves with immense water supplies from outside their own area. The same kind of progress, as social conditions change, is produced in other things beside water-supply. Last autumn, at the time of the British Association meeting at Bradford, I was inquiring into some of the conditions which affected, or would affect, the supplying of power in Bradford, and one that is not to be despised in considering the question of area is this: In the town of Bradford practically the whole of the industries that require power are textile industries, and all the mills practically begin work and leave off work at the same time. Any one who knows anything about electrical supply companies knows that that is not the most favourable condition

Professor Silvanus Thompson.

for the supply of electricity; for you get a load-factor which is undesirable, as in the case of lighting, when all the light comes on or goes off at the same time. It is really much better to have a consuming element which takes power from the station for a variety of industries which do not all start off at the same time, or stop at the same time. Therefore, in determining the area which would be economical for the supply of electric power, it is inadvisable to confine that area to a place where the industries are all of one kind. It would obviously be more economical to include other towns with the town that had one industry—other towns which had other industries which do not want the supply at precisely the same time, because every one knows that what will fill up the gaps in the electric light load between the demand of one consumer and that of another, is all to the good of that electric lighting station, and improves its load-factor. When we compare the state of things in Italy, for example—a relatively poor country, a country very far behind in many ways—and see how, in Italy, station after station has been built, each station with very large generating machinery distributing power over wide areas, one feels perfectly ashamed of what is going on in our own country. I found in Bradford a firm which supplies power-looms to the textile industries of Lombardy, and had supplied some thousands of looms quite recently, within the last year or two, every loom being fitted up with an electric motor, I believe in ninety-nine cases out of the hundred with a three-phase motor on the end of that loom. They were supplied from Bradford, the very centre of our English textile industry, yet the same firm has not supplied a single loom fitted up with an electric motor for this country! It is most astonishing that we should be sending to Italy, to compete with us, looms electrically fitted, because they have an electric supply, and that in Bradford there is not a single loom fitted in that way. I leave you to consider why.

We have been told that we are a nation of amateurs. The reader of this paper has emphasised that point. But I do not quite agree with him in thinking that it is a matter to be lightly thought of, that we do not put the same store on education as some other nations. If you will go to one of the large factories that send over machinery to this country from the United States you will discover that practically every man in that factory above the grade of fitter is a college graduate. They do not turn a man away there because he is a college graduate, or sneer at him as being unpractical. No, they welcome him, and take him in, and make the best of him, with the result we all know. In Germany and in Switzerland one knows that throughout the factory, in every department, you will find as managers of the different branches men who have received the highest scientific and technical training. It is brains really against which we have to fight, alike in the case of the German, the Swiss, and American competition in these matters. They do not leave things to be "muddled out." They do not leave them to be done in an amateurish way. They think it out beforehand, and they take the best-trained brains and make the most use of them.

One argument that I have found very effective in talking to the people who think that a little electric light station can supply power in each

Professor Silvanus Thompson.

little town up and down the country without any big power-scheme, is this: See what has happened in London. In London we began with our Vestries and Companies putting down little stations here and there, one in each of our parishes. Gradually these things are coming right, and are being altered. We are finding that a central station is an absurdity, that no station ought to be central, that all ought to be out of the centre, that they ought to be outside; that we ought not to have to be carting coals into the middle of a great population, and carting ashes out again; that the economical place to put the station is outside, and that a few large stations outside are paying better than a great many little stations each in its own district. When you point out that, then the doubter begins to see that a large supply station serving a large area is really a much more economical thing than a number of little stations dotted down in the different towns.

May I conclude with a parable? Walk down Aldgate, and you will see the pump, the famous Aldgate pump, surviving to this day, and reminding us of the time when each little bit of a parish had its own water-supply. The time is not far distant when any Vestry Electric Station, or any petty little town station, will be looked upon as just as absurd for the purpose of a big power-supply to the industries that want mechanical power cheap, as the Aldgate pump is for supplying water to London.

The President.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Member:

Montague Brown Mountain.

Associate Members:

Henry William Clothier.
Matthew Clavering Coates.
Henry William Wartnaby Dix.
Alfred Ernest Kennard.
David Henry Kennedy.
Frederick Joseph Arundel Matthews.
John McLellan.
John Frederick Nielson.
Arthur Peckett.
Herbert William Sprunt.
Noel Statham.
John Erskine Meysey Stewart.
John William Towle.
Charles Tuson.
Henry Dewar Wight.

Associates:

Harold John Bullock.
Frederick Thomas Callis.
Charles James Carter.
Charles Henry de Russett.
Arthur William Fithian.
Thomas Gemmel.
Thomas John Grainger.
John Angus Hay.
Colin Bell Heaviside.
Mukand Lal.
Donald Macdougal Macbean.
Colin Campbell Macmillan.
Stephen George Martin.
William Odgers.
John Edmund Pownall.
William Pummell.
Bernard Rance.
Frederick Rawlings.
Maurice Hugh Reynolds.
Lionel Inglis Robinson.
Edward Alexander Savage.
Walter Simpson.

Henry Beven Swift.
Thomas Fane Tebbutt.
H. Arthur Thomson.
Alexander Houston Weddell.
Richard Ffolliott Willis (Capt., R.M.L.I.).
Herbert William Wilson.

Students:

Herbert Addy.
Ellis Amos.
Herbert Dudley Ash.
Claude Randolph Barry.
Frederick Edmund Berry.
Edward George Paul Bousfield.
Swinfern Bramley-Moore.
Jeoffrey Thorold Brookes.
Harold Thomas Brown.
Samuel Wilfred Carty.
Edwin Olding Chadwick.
Albert Bernard Clark.
Benjamin Charles Colley.
William Michael Conway.
Denis Cullen.
John Stewart Dow.
Hugh Victor Diamond.
Percy Farmer Draycott.
Alfred George Ellis.
Christmas Llewellyn Evans.
Thomas R. R. Gaunt.
Edward Lind Gosset.
Charles Ernest Greenslade.
Herbert Ernest Hart.
Thomas Hopper.
Hugh Arnold Hughes.
Walter Ings.
Albert Henry Jackson.
Henry William Jones.
Frederick Edward Kennard.
William John Kinnersley.
Raymond Vincent Marriner.
Arthur John Martin.
John Edward Medley.
Percy George Mitchell.
Ernest Josias Nichols.
Patrick O'Hara.
Henry Arthur Pickett.
Amos William Pulvertaft.
Frederick Charles Purvis.
William Bradley Randell.
Thomas Raven.
Ronald Morrice Robertson.
Lionel George Frank Routledge.
Herbert Samuel Selves.
Arthur Greystone Shearer.
Ernest William Short.
Percy Rayner-Smith.
Samuel William Steane.
Walter Alexander Turnbull.
Stanley Thomas Walker.
Arthur Percy Whitehead.
George Wyatt.
Arthur Primrose Young.

The Three Hundred and Fifty-Ninth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, February 28, 1901. —Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on February 21st, 1901, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that the list should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Members—

Michael Birt Field.

From the class of Associates to that of Associate Members—

Albert W. Makovski.
G. C. F. Székács.

Donations to the *Building Fund* were announced as having been received since the last meeting from A. D. Williamson, H. B. Graham, C. Poulsen, A. H. Unwin, J. W. Manley, and Captain R. Willis ; and to the *Benevolent Fund* from C. J. Carter, R. J. Wallis Jones, and Captain R. Willis, to whom the thanks of the meeting were duly accorded.

Mr. H. W. K. Irvine and Mr. R. P. Brousson were appointed Scrutineers of the ballot for the election of new members.

Professor W. E. AYRTON : I rise to propose no ordinary vote of condolence. For in expressing in conventional form the sincere regret which this Institution feels in the death of the Chairman of its Dublin Local Section, I desire rather to give voice to our deep grief and sorrow at the loss of the dear friend of many, and the willing helper of us all.

To some of you, perhaps, Fitzgerald was but a name, and why? Because his life's work was that of inspiration—inspiring others. He gave them his ideas, aye, he even explained to them the real meaning of their own. Science to Fitzgerald was what religion is to the highest type of priest—not a thing to be used to enhance the status or the wealth of its exponent, but as a great good to be poured forth without stint and without reference to reward or even recognition, for the benefit of man and of the world. Singularly free of all human ambition, singularly fertile in suggestion on all subjects, was our dead comrade. He knew his worth, but never claimed it. He knew his power, yet, whene'er he used it, it was for you, for me, for science, to secure intellectual liberty, but never to secure position for Fitzgerald. And yet for him abstruse mathematics had no difficulty, complex physical processes no obscurity. He seemed to be able to follow the interaction of invisible molecules more easily than we can grasp the working of visible machines. This morning I was looking at two letters from him, one which reached me the very day that Mr. Duddell read his paper in this room in December, and the other a few days later. Every line breathes suggestion, encouragement, criticism, modification. Why, those two letters are a little treatise on the theory and the possibility of Mr. Duddell's devices. Single-minded, simple-hearted, he died as he lived, respected, honoured, beloved.

General C. E. WEBBER: I cannot pretend to follow such an eloquent discourse as you have just heard from Professor Ayrton, but I would say that there is a feature in connection with our dear late friend, Professor Fitzgerald, as regards what produced that man, which is of some interest. Although heredity may not be strictly scientific, it is a subject which attracts us all. Professor Fitzgerald could trace his ancestry back to the Normans who, starting from Scandinavia, conquered Normandy, conquered Italy, conquered England, and finally conquered Ireland. There can be little doubt that the brain work which we have just heard described, emanated from tissue that was strengthened and was brought down to him through generations of strong and powerful men. But not only was he strong. He was essentially a man who

was entitled to be called gentle. Gentlemen, I beg to second the motion which will be read to you by Professor Ayrton.

Professor SILVANUS THOMPSON: I wish to add my voice to that of Professor Ayrton and General Webber in expressing condolence with the loss of one who was so dear to us personally, and so very helpful to every worker in science who had the good fortune to know him, however slightly. Not very long ago I was talking with some of the scientific men of Germany, and they were deploring that they did not, or could not, do in Germany that which is done so very effectively in England by the combined efforts of scientific men working together in Committees. They instanced the Committees of our British Association as examples of the voluntary associations which did from time to time excellent work, carrying that work on in continuity from year to year in a way which did not happen in Germany, where the only combined kind of effort was that which was done under the patronage either of the Government or of one of the Universities, and mostly by paid workers. Among the members of the British Association, whose help on Committees of that kind when organising scientific work to be carried out during the course of a year, if there was one more helpful than another it was Fitzgerald. We ought not to forget what a very important part Fitzgerald's ideas played in the early development of the question of the production of electric waves. Before the researches of Hertz, which resulted in the experimental methods of exploring electric waves, Fitzgerald had read at least two papers before Sections of the British Association, suggesting ways in which such waves might actually be started; in fact, suggesting beforehand that which Hertz accomplished, and predicting for us the generation of these waves on the lines of Maxwell's investigation. I believe I am right in saying also that one of the suggestions for a coherer for detecting waves, if not actually the first, was made by Fitzgerald himself. In thousands of ways did he help others to carry out ideas, and gave them ideas to carry out; ideas which he could very well have carried out himself. But his mind was so fertile that he could not possibly, even had he had the time at his disposal, have

carried out one-twentieth part of the brilliant suggestions that he gave freely to others and to the scientific world. He was a man who was to a certain extent overloaded with administrative and educational work that ought never to have been put upon him. He ought to have had freedom for research, and ample means for carrying out researches. Whatever he did he touched with the finger of genius. There are few of us who may claim in any sense of the word to have been workers in physics in the last fifteen years, who do not feel a debt to Professor Fitzgerald. I had the good fortune to be associated with him very closely during the last three years in quite a different branch, namely, as co-examiner with him in the University of London. And even in the routine work of examining candidates for their degree in physics, Fitzgerald was as fertile in suggestion, as kindly, as helpful, as any man could possibly have been. A truer or better colleague in that capacity one could not have desired. I remember very well indeed being struck with the pains with which he read through, and referred in detail to, and made careful investigations himself about, the theses which were presented for the Doctorate of Science by candidates in physics. It was characteristic of the man that when sitting as critic upon a work presented as a thesis for examination, he should act as helpful critic, and as a man of useful suggestion. There are few men in this world like Fitzgerald: there are few indeed who can claim the ability in any walk of life which Fitzgerald exercised in the highest branches of physics: there are few who equalled him, none whom I ever met who surpassed him, in kindly helpfulness to others.

The PRESIDENT: At the inaugural meeting of the Birmingham Local Section of this Institution last night, I said what I have to say to the Institution on this subject. It will be printed, I hope, in the Journal. I should have gone to Dublin on Tuesday for personal reasons, but I went to Dublin as representing the Institution at the funeral. It only remains for me to read Professor's Ayrton's motion to the meeting:—

"That the Institution of Electrical Engineers, in full Meeting, desires to express its profound sorrow at the death of Professor George Francis Fitzgerald, and to place on

record its high appreciation of his brilliant qualities as a man, as an investigator, and as a leader of scientific thought and to express to Mrs. Fitzgerald and his family their heartfelt sympathy under the calamity which has fallen on them and on Science."

The resolution was carried in silence, all present standing.

The President.

The PRESIDENT: I will now call upon Mr. Hammond to resume the discussion on Mr. Madgen's paper.

Mr. Hammond.

Mr. R. HAMMOND: During the discussion on the Power Bills last session, before Sir James Kitson's Committee, some vitally interesting engineering questions arose in connection with the generation of electrical energy at centres, and the distribution of that energy over large areas. Those questions still await discussion and decision. I have made a note of one or two of them. What is the limit of distance from the generating works of supply to consumers, beyond which the extra costs of distribution counter-balance the advantages of concentration of plant? What is the limit of kilowatts installed in a central station, beyond which economy of centralisation of plant ceases? That question arose on more than one of the Bills, and there was a very great difference of opinion with regard to it. There were those who urged that beyond 5,000 kws. there was little advantage in concentration; there were those who urged that beyond 10,000 kws. there was little advantage; and there were those who urged that you might go on almost indefinitely, and that every time you put down plant for another thousand kilowatts you gained an advantage in cost of production. I say that that is a question which would form a very interesting one to discuss in this room. Thirdly: What are the means that are going to be adopted in order to preserve over a large area, with various consumers, large and small, pulling at the line, uniformity of pressure so as to be able to give electric light within, I will not say Board of Trade limits, because this paper does not like the Board of Trade, but I will say within efficient limits? I am sure that we all feel that when we take a residence in the North of London, and we are supplied from the Northern Metropolitan Power Company, we shall not like our light to be pumping up and down, and we shall certainly have a right to consider before we turn it on what are the means that are going to be adopted in order to give us just that little variation of pressure which we, as electrical engineers, can put up with. I mention those three points, each one of which I think could very seriously occupy the attention of this Institution. They are certainly within its direct scope, and I feel confident that when the engineering questions arising out of these Power Bills are discussed, our guests from the country will find this room full to overflowing. To-night we are dealing with a different subject. This paper has an excellent title, "The Electrical Power Bills of 1900: Before and After," but not one of the engineering questions which we, as electrical engineers, are interested in, is touched in this paper. That leaves a chance for somebody else who is interested in the

Mr. Hammond

engineering side of the question to come up with another paper—that will be "The Electrical Power Bills of 1900: After," leaving out the "Before." This paper, I think, may be summed up under about four headings, and these four points are, I conceive: (1) in the first few pages, a lament, a dirge I may say, over the fact that we in the United Kingdom are terribly behind in the matter of electric lighting, fortified by certain extracts written by the most irresponsible persons in most irresponsible daily papers; (2) an intimation that this backwardness in electric lighting is due to the ignorant Legislature, the foolish Board of Trade, and the selfish local authorities; (3) an intimation that what we should do is to copy the German and American methods; and (4) an appeal to this Institution, fortified by chapter and verse out of its Articles and Memorandum of Association, to form a committee in order to make the path of the Company promoter at all events a little smoother. As far as I am concerned, I am very sorry I was not at the reading of the paper, because I should have liked to get in at a very early part of it. I was professionally engaged elsewhere, but I understand that almost all the speeches were thoroughly in support of the paper. Therefore, I am glad to be here to-night, to say that I distinctly dissent from those four propositions, though, of course, there may be more than four in the paper that I dissent from. I will take the first. Why are we behind in this country in the matter of electric lighting? The paper gives certain explanations. I deny the soundness of those explanations. Why are we behind? Let any electrical engineer in this room who has had to face a Board of Directors desiring to put their money into electric lighting (or unwilling, as the case may be, but anxious at all events to make a good investment), say why; or let him face a committee of a Town Council equally desirous of extending the town investments, but not wishing to make a mistake, and then give his opinion on the subject. What is the feature that has kept us so far backward. It seems to me to be the A B C of the subject. Those of us who have passed through it have always been met with one point, and that is, we cannot compete with gas at 2s. a thousand feet. That was said to me by a number of capitalists in Leeds ten years ago, and the result was that they delayed starting works. When I went to the Corporation, and tried to persuade them, they equally dissented, because gas at 2s. a thousand feet could not be competed with, and over and over again in this country up to the present time the spread of electric light is checked by the keen competition with the cheapest gas in the world. People have come back from their summer holidays and told me over the dinner-table that they have been at a small village in Switzerland, and they have seen the electricity in the rooms of their hotel. But how is it? It is because they cannot get gas at any price. When I first went to New York I found gas costing 10s. a thousand feet, and I was not surprised that Mr. Edison was doing so well with his electric light. Throughout America and on the Continent you find high prices of gas. I took my Dublin friends across last year to the Continent, and there was one man who would ask, "What is the price of gas?" And when he found that it was 6s. or 6s. 6d. he was amazed. The real factor in the backwardness of electric light in this

Mr. Hammond.

country is not the factor mentioned by Mr. Madgen, but the cheap price of gas. Mr. Madgen says that it is all due, or almost all due, to local authorities. I ask you to say that that is an absolutely mistaken idea to nourish. Local authorities in this country, out of investments amounting to twenty-five million pounds, have put down fourteen million pounds. We owe as an Institution a great debt of gratitude to the local authorities in this country, for the customer who comes and puts fourteen out of twenty-five millions into an industry is a desirable customer and we, as electrical engineers, owe him a debt of gratitude. As for the consumers, the local authorities have shown the companies how electricity can be produced at a low rate. Their average rates of charge are far lower than those of companies. There are two undertakings in the country that supply at below 3d., and both are local authorities. There are 6 that supply between 3d. and 3½d. None of them are companies. There are 12 that supply between 3½d. and 4d.—nine local authorities and three companies. There are 30 that supply between 4d. below 4½d.—25 local authorities and 5 companies. There are 23 supplying at 5d.—18 local authorities and 5 companies. If I had time I would carry the point further, and show, when you get above 5d., how largely the companies exceed the price of the local authorities. Now for Germany. I say with regard to Germany, let us do as the Germans do. My work has taken me three times to Germany this year, and I have gone from one central station to the other, and I will tell you what you are likely to see when you get there. With regard to the wonderful power schemes in working order mentioned by the author, you will not see one. You cross the frontier at Aix-la-Chapelle, and you will find that the works are owned by the Municipality. You stop the first night at Hanover. You go on to Dresden, and you put in a few hours at Nuremburg. You stay at Frankfort, and then you go to Mayence—and in every case you find that the works are owned by the Municipality, Finally you stop for a night at Mannheim, and discover that there is there a big power scheme supplied by the Municipality. Finally, I disagree with Mr. Madgen, who says that we want a committee to put these local authorities right, and to straighten out the Legislature. No, better far for some member—I will not, as I am on the Council—to move an amendment that a committee be formed to consider engineering questions connected with power supply, and to report to the Institution to what extent the present power schemes are likely to overcome them.

Mr. Morse.

Mr. S. MORSE : I hoped to have spoken later in the evening, but it is perhaps as well that some one should at once get up to suggest to the last speaker that his speech was one which it would have been better to have left undelivered. I regret that it was put forward by the last speaker that he would not, by reason of the fact that he was a member of the Council, move an amendment. I should have said he did not dare move an amendment. I know no reason whatever—and I have been a member of the Council myself—to prevent a member of the Council moving an amendment to a resolution moved by members of the Institution. I should have thought that if a member of the Council felt a strong opinion upon any matter, it was his duty, as well as his privilege, to move the amendment.

I have had an opportunity for some years of knowing something about what has been going on in these matters, and I say without hesitation, or without fear of contradiction—because I do not attach the slightest weight to what has fallen from Mr. Hammond on the point—that the present position of the electrical industry of the country is largely due to the unreasonable difficulties put in the way of its progress by local authorities. I should not have discussed the matter from this point of view if it had not been for the remarks made by the last speaker. He has chosen to put it forward: and no one can deny that our backwardness is almost entirely due to those difficulties. I agree that Parliament also is partly responsible, but it must be known to members here to-night that the local authorities have gone further than acting merely within their own districts as regards what ought to be the welfare of those districts, and have entered into such an alliance as ought not to be permitted, and have put great pressure upon Members of Parliament, when matters of this sort have come before Parliament for discussion. I am not an electrical engineer, but I do know this, that it is essential for an industry of this kind that there should be available to every manufacturer throughout the country a supply of cheap power, available to him at all times of the day and night, at rates which will enable him to compete with his foreign competitor. Why is not that here to-day? It is not because gentlemen have not the means at their disposal, and have not taken steps to obtain those powers. Every effort has been made, and what has been the bugbear to stop it? The local authorities. Look at what happened at the second reading of the Power Bills last session. What is the desire of engineers here? It is, I submit, that electrical engineering should have fair play, free play, and that schemes should be discussed on their merits. If the local authorities will agree to that proposition, instead of private companies only having a total capital of 11 millions out of 25 millions invested in such enterprises, we shall have a total of more like 250 millions. I am astonished at any one in the position which Mr. Hammond holds saying that 14 millions spent by local authorities in this country is a large sum. It is an extremely small and insignificant sum, and one which makes the traders of this country ashamed of the position which they hold in the world. I do feel very strongly that we are here dealing with a question of the utmost importance. I do trust the Institution will put forward, as the word which should go forth to all parties in the matter, their opinion that the trade should have free play. Let the traders have a right to have their schemes discussed upon merits, and abolish the veto which unreasonably and improperly has been given to local authorities to prevent that being done.

Mr. G. L. ADDENBROOKE: It is rather difficult to speak at this stage of the discussion. After having had, I think, almost as long an experience as any one of work on these large power schemes, I may say I am very largely in agreement with Mr. Hammond, at any rate as regards his facts. The only thing is, I think he has drawn the wrong inference from them. It must also be pointed out that Mr. Hammond was discussing electric lighting altogether as if electric power had only Mr. Addenbrooke.

Mr. Addenbrooke. just come in. But electric power has been applied on the Continent and in America for seven or eight years now, whereas we have practically done nothing in this country. We are not discussing electric lighting at all. I quite agree with Mr. Hammond that English electric lighting has had enormous obstacles to overcome; but whether the municipalities have overcome it better than the companies would have done is another matter. I agree with Mr. Morse that if private enterprise had been conducted under proper regulations, which might have been drawn up, it would have advanced a great deal further than it has done. Mr. Pember told me some three years ago, that he was confident proper regulations, which would put private enterprise and municipal interests on a fair basis could be arranged. If such an Act had been passed in the early days instead of the Electric Lighting Act, we should have had far more than £25,000,000 invested in enterprise connected with electrical industries. The way in which electrical enterprise has been trammelled has been shown by these Power Bills. Notwithstanding, as Mr. Hammond says, that they may be very speculative enterprises—as undoubtedly they are from many points of view—and there are enormous difficulties to be faced in the way of dealing with local authorities—yet the moment there was an opening, English capital has been ready to embark on the venture. I have made a rough calculation that by the end of this session, more than £100,000 will have been spent merely in the promotion of those Bills. It is perfectly true, as Mr. Hammond says, that you may go to Germany and Switzerland and find things existing as he told you. I have made many careful inquiries as to their power schemes. When I was engaged on the Midland Power Scheme, I was asked to go abroad to report on the Continental work which would bear on it. I first of all met Mr. Kapp in Germany and talked the matter over with him, and afterwards, by his advice, went to certain places in Germany and Switzerland. I showed the various people the plans of what we proposed to do; I showed them to Messrs. Brown Boveri, and to the Oerlikon people, and said I wanted to carry out a project of this sort, without overhead wires, but with cables, and asked what they had to show me that was most like this. I may say that there was a great deal of difficulty in showing me exactly the same thing. It has always been my feeling from the very first that conditions in England are different from those on the Continent, and in America—that in these Power Bills we were meeting a set of local conditions, and a problem of our own, and that if we met that problem as I feel confident we are now meeting it, we should be in the front rank again of enterprise and in the benefit which we should confer on the country. Mr. Hammond, therefore, is right that this is a difficulty. You may see hundreds of waterfalls here and there with a local line of transmission; but only at Rheinfelden and one or two other places did I see that kind of scheme which we are trying to work out of having large power stations in the centre, and a large industrial population round about it. That is an English proposition. It naturally follows, that if you can supply power to one portion of the circle, you can supply it all round. I should have thought the proposition was self-evident. Mr. Hammond was right in saying that we have an

individual problem. We ought to be proud that we have something to do with it. It would be a grand thing if local authorities and Parliament would help those who are trying to place England again in a good position in the manufacturing world. With regard to the questions which Mr. Hammond mentioned as suitable for discussion by the Institution, they are of course most important questions. I have spent years upon them, and my feeling about these power schemes, is that every one must be considered on its own merits. They are great undertakings, most complicated, with varying conditions, depending on numberless circumstances which you cannot treat generally. All you can do is to secure a body of men who have, or who ought to have, a knowledge of their profession, and who, in consultation say this ought to succeed, and who then, like Englishmen in the old days, put down their work and their money and tried to make the thing go. That is the way in which this country has been built up, and unless the local authorities can see absolute detriment to themselves, or that the work that is to be done by the public companies is an absolute disadvantage to them, a free hand as far as possible should be allowed. We do not want monopoly. We are perfectly prepared for the local authorities to set up their own electric-lighting stations and run their own mains into all our customers' houses if they like. I do not agree with everything that is done by those promoting power-schemes; but those who have gone into the question feel confident that the principle on which they are working is to a large extent right. Even if it is wrong, if people are willing to stake their money on it I do not think it is the business of anybody else to say that they shall not, if by doing so they confer, as undoubtedly they would, an enormous benefit on the district. If they choose to throw their money away on the district, that is their concern. Mr. Addenbrooke.

I have travelled a great deal in the Colonies and about different parts of the world, and I am certain of the wonderful development which will take place due to this power work. I could tell you stories, if there were time, of the difficulties of transport and other matters which can be got over by electric transmission. We are not permitted to have any opportunities of true electric transmission in this country. We are so hampered by conditions that any scheme carried out in this country would not be anything like electrical transmission of power in other parts of the world. People come from different parts of the world, and say they want so and so, and ask what we can do? We have nothing that we can show them here, but are obliged to refer to some American or German account of a scheme that has been carried out abroad. That is the position I have been placed in in working for Australia and Africa; and I myself have had to go to America and Germany for the materials with which to carry out the work.

Mr. E. GARCKE: The great difficulty in discussing questions of this complexity always is to find people who have sufficient versatility of experience to take a fair-minded view. I was exceedingly disappointed, therefore, to hear the speech of Mr. Hammond, because if any gentleman in this room has had a varied experience of this industry it is Mr. Hammond. I had hoped that the very large and varied experience Mr. Garcke.

Mr. Garcke. which Mr. Hammond had gained in so many different branches of industry would have enabled him to give us the benefit of a fair-minded view of this very difficult and complex question. What did he do? He started off by pointing out that Mr. Madgen had offered four particular reasons why this industry was more backward in this country than in foreign countries, and he promised to give us an answer to each. It is true he only had ten minutes, but he confined himself to answering only the first of his propositions, and in attempting to answer that he offered explanations which I hold to be misleading to the younger members of this Institution. They were not so to me, nor to Mr. Morse, nor, I am sure, were they so to his fellow-members on the Council, but to a large number of students, the rising generation of this important industry, I think that Mr. Hammond might have rendered this industry and this Institution a higher and a better service. What did he say? He wanted us to understand that the Corporations had been customers of the electrical industry to the extent of fourteen millions, and implied that, if the Corporations had not expended that capital, that capital would never have been expended. Why should we owe any debt of gratitude to local authorities for that capital when, as a matter of fact, we, as capitalists, were prepared to spend that capital, and would have spent it five or six years earlier? It is not simply the amount of capital that they have expended, but it is the tardy and vacillating manner in which they have proceeded with the work. I do not wish to enter upon the question of municipalisation, for and against, it is not germane to the discussion; but there is one very important aspect which ought to be mentioned whenever the question of municipalisation is touched upon. And having said the few words on the subject that I have said, I must not sit down without saying in the most forcible language that I can use, that I am strongly in favour of municipal enterprise, and always have been. I advocate the higher development of the municipal function. I think it is the duty of ratepayers in their collective capacity to do whatever they can for the promotion of the health, the happiness, and the material comforts of their districts, but I say it is not one of the functions of municipalities or of local government to effect a transfer of the profits of trade from private companies to the collective capacity of local authorities. The function of the Government is an entirely different one. If once we ignore this, I may say, elementary economic principle of expecting the whole of our trading profits to be made by municipalities, and allow the local authorities to become the common traders of this country, there will very soon be a limit to all enterprise. I repeat again, that I express that view in opposition to municipal trading, notwithstanding that I am a most ardent and consistent advocate of municipal enterprise. I hope I have made the distinction between those two phrases perfectly clear.

What did Mr. Hammond say about the real reason why electric lighting had not developed more quickly in this country? The price of gas!—The price of gas was so low that electricity could not compete with it. Are not the millions of electric lamps that have already been installed competing with cheap gas?

Mr. HAMMOND: I meant as compared with the price: I quite approve of the competition. Mr. Hammond.

Mr. GARCKE: If I had the time I would undertake to refute the statement that gas has been any obstacle to the introduction of electric light. I remember Sir William Preece saying that the electric light was capable of being made the poor man's light, and I have preached that doctrine throughout the country, and I have heard Mr. Hammond do the same, and yet we are told that the low price of gas is a preventative to the development of the electric light. I say it is a most misleading statement. Then another argument that Mr. Hammond used was, that Corporations had supplied electric light at a lower rate than Companies. But the whole of my argument is, that if Corporations undertake to supply electric light at all they should do it in the common interests of the community, and do so, if the ratepayers wish it, for nothing. Mr. Garcke.

That is the ideal development of municipal enterprise, and therefore, the lower they go down in the price of electricity the better they are doing their work. It is on those grounds that I say municipalities are able to carry out many of these public services better than companies. But there is a period in every industry, and we have gone through it in the electrical industry, when local authorities are not able to take up the speculative risks of entering upon a new industry, and during that period it has to be undertaken by private enterprise. Private enterprise should, while it undertakes these risks, be encouraged, and not, as has been the case in this country, discouraged by the local authorities. Then Mr. Hammond referred to the Continent. But he did not tell you how the local authorities behave in that country towards private enterprise. There is absolutely no discouragement of private enterprise, notwithstanding that there is municipal enterprise.

The paper which we are discussing is an exceedingly interesting one, and the questions which it contains as to why England is backward in electrical industry—that it is backward I do not think there can be any possible doubt—but the reasons why it is, are due to a plurality of causes, and it is very difficult indeed in the course of a few minutes to refer to all the social, political, and enconomical reasons which go to make up the causes for the backwardness of the country.

Professor W. E. AYRTON: On the last occasion some of the speakers prefaced their remarks by saying: "*Although* this Institution is a scientific Society," &c. I should start quite differently, and not say "although," but "*because* this Institution is a scientific Society, therefore the paper which Mr. Madgen has contributed is one well worthy of our most careful consideration." For it is a great mistake to imagine that the science of electrical engineering is alone concerned with formulæ or equations, or with Ohm's or Kirschoff's law, or at the best with electrical experiments in a laboratory. I take it that the science of electrical engineering comprises the application of correct reasoning to all that appertains to the professional welfare of the electrical engineer. But, mind, I said the application of correct reasoning. For it is just as easy to reason wrongly about a Power Bill, as about the power used in dielectric hysteresis. It appeared, I venture to think, that there was Professor Ayrton.

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a certain obscurity of logic characterising the eloquent speeches that we heard last Thursday, when it was endeavoured to be proved that the electric backwardness of our country arose wholly from local obstruction—the obstruction of local authorities. Now, I propose to inquire if that charge is well founded. I am not here in any sense as a champion of officialism, and nobody has been more anxious for a long time past than I have been to see a wide development of electrical transmission of power. But there is no reason why, because the almost Utopian dream that I and others suggested in 1879, and put twenty-two years ago before some thousands of workmen in Sheffield—a dream that "each workman would have electrical energy laid on at his hand, would have transmitted to him, just at the time he might require it, a small amount of energy, at say a halfpenny per hour per horse-power," which he would be able to turn off like gas when he did not require it—has not yet been realised, that we should blind ourselves to the real cause of our position. Let us take as an example the Metropolitan Railway, some considerable portion of which I saw being constructed nearly forty years ago. Why are the trains not being run by electricity? Is it because of some restriction imposed? Is not the stagnation rather due to the lethargy of the chairman and directors of a private company, the sort of company that we were assured last Thursday would rejuvenate Great Britain? Why, the Bill to sanction running the Inner Circle electrically became an Act of Parliament four years ago—and yet, and yet! Now take another example—they are endless. Going the other day through a large electrical engineering works, I saw being made the iron cores of field magnets. They were being made from cast-steel obtained from Germany, and were being tooled by machinery obtained from America. Was that because of some restriction by some local authority? Was it not because the owner of that factory in England thought, rightly or wrongly, that he could get better cast-steel for field magnets in Germany, and better machines to work it with in America than he could in his own country? Coming to this question of distribution of electrical power, I ask you, Is it a fact that in those districts which are under the control of a Municipality electric energy is always dear, and in other places, where private companies rule, that it is cheap? Mr. Swinton asks me what that has to do with it. I will take an example, because examples are very valuable. A certain local authority wished to light its own borough electrically—a small borough. They got out plans for a boiler-house, engines, dynamos, etc. But within two and three-quarter miles of the boundary of their district a very large generating station was being put up by a very important private company. This seemed to me a favourable opportunity to carry out the idea of transmission of electrical energy. So when I was consulted, I suggested to the local authority, not to lay the foundation-stone of a central station, but to let me arrange for them with the great central station, one hundred times as big as theirs could be, to send the electrical energy "in bulk" (as it was called) to the boundary of their district. The Local Authority accepted my advice, and asked me to carry out the negotiations! There was no difficulty about way-

leaves; there was no difficulty of any kind; all of us were the most excellent friends. I informed the private company that they might use any system of transmission they liked, either one, two, or three phase, and transmit at any pressure they wished, the only stipulation was that at the boundary of the district they should transform it into two hundred volts direct current. Only a small amount was required to start with—some 500 H.P. Still, as we only wanted it at one place, and the local authority was to do all the distribution and the collection of the bills for electric lighting, as far as the private company was concerned it was exactly as if the local authority was a factory requiring 500 H.P. at one particular place. What was the result? It was not a question of want of legal power. The Company said that they had gone into the question carefully, and frankly assured me that even if we made a contract for ten years to take the whole supply of energy that the local authority might require, whatever it should grow to, they could not undertake to deliver it to us at the boundary of our district at under 3d. a Board of Trade unit. Of course we replied that we could not take the current, because it was cheaper to cart coal into the district and put up a generating station. That leads me to the very important question of the relative cost of carting coal and transmitting the energy through cables. With water-power it is quite different. In a place where there is no coal, and there is water-power, you can only transmit power, if you want to use that power, by the use of electrical methods or other methods, such as compressed air, or whatever you like. For it is hopeless to carry the water in waggons as the Great Eastern Railway brings sea-water, because if you do so you leave the energy behind. But in the case of coal, there is another way of transmitting energy, and that is in waggons. I won't trouble you with figures, but I have got wholesale estimates, tenders, for the carriage of coal from all parts of this country to other parts, and speaking as an electrical engineer I am extremely sorry to see the prices come out so low. It seems to be a fact that it is cheaper to carry the coal than to transmit the energy electrically, for say twenty miles, if underground cables and a maximum P.D. of 10,000 volts are allowable. Professor Ayrton.

Mr. C. B. CLAY: I am told I am a bold man to speak at this Institution, especially on a subject on which I am afraid I am not as well qualified to speak as most members; but I think that the experience that has been obtained in one branch of the electrical profession may be worth recording in a meeting such as this. At the last meeting of the Institution the position of the electrical profession with regard to legislation and to municipal competition and obstruction was dealt with by several speakers. First, with regard to Government obstructions, I should like to read two or three short extracts from an article which appeared in the *Times* of the 13th of June, 1884, and to call your attention specially to the moral which is drawn by the writer at the end of this leading article. The *Times* says: "It appears . . . that the action of the Post Office has been so directed as to throw every possible difficulty in the way of the development of the telephone and of its constant employment by the public. We say advisedly 'every possible difficulty, Mr. Clay.

Mr. Clay. because the regulations under which licences have been granted to the telephone companies are, in many respects, as completely prohibitory as an absolute refusal of them. . . . It appears that the telephones can only be used under restrictions which are as absurd as they are vexatious." And, further on, it says: "The conduct of the Office, although not legally dishonest, is at least morally indefensible. There can be no just ground for a claim to possess the telephone by virtue of words introduced into an Act of Parliament before the telephone was thought of; and the effects of this claim are nearly as disastrous to the public as to the inventors and owners of the instruments. . . . It is much to be wished that Parliament could find time to liberate the telephone from the bonds of red tape in which it is being strangled, and to allow its future to be shaped by the operation of the ordinary laws of political economy. In the meanwhile, and even when this desirable release has been effected, it will be prudent not to lose sight of the moral of the story. This is, if anything, that the practical applications of science cannot be safely or prosperously committed to the hands of a Government framed upon the model of our own." Mr. Raworth pointed out at the last meeting that companies had nothing whatever to fear from municipal competition on equal terms. I cordially agree with that. I have been fighting the opposition for many years, and I have never yet been beaten on equal terms, and I have never been beaten on unequal terms—very unequal terms in many cases. The whole point of the matter is thus equality. I propose to show that the same spirit which prevailed sixteen years ago, when this article was written, appears to be ruling our Government now. The history of the telephone branch of electrical engineering is a history of one long fight by the companies to be allowed to serve the public. In looking over some old papers, it seemed to me almost impossible to believe that at one time we were allowed to open call-offices at which a member of the public might go to speak to any subscriber, but one of the conditions on which we were allowed to do that was that we must charge a shilling, of which one-half was to go to the Government. It is needless to say what was the result of that. Then another thing with regard to trunk-working, communication over the trunk-wires was only allowed to subscribers at both ends, and then each must be a subscriber to the trunk-wire. For instance, taking from London to Brighton, a distance of about fifty miles, the charge fixed by the Department was £25; the subscribers in London paid £20 and the subscribers in Brighton £12. Therefore, to have any useful communication between Brighton and London, the subscribers between them had to pay £82—a rental of no less than ten shillings for each mile of wire. Then the company wanted to connect up post-offices, so that subscribers could forward telegrams. The Post Office, however, although they gave this facility to their own subscribers free, imposed a charge upon the company of five guineas per subscriber, which of course killed the business. This charge was eventually done away with, and for some years connection with post-offices was allowed. It has very recently been refused in the case of one of the London Exchanges, so that the subscribers are not allowed the facility on any terms. With

reference to the competition with the companies, Mr. Fawcett stated: "When that competition has gone on for some time, the Government would be able to judge who did the telephone business best. If it were done better by the private companies than by the Post Office, the Department would be delighted to have the whole telephone business of the country conducted by private enterprise. If, on the other hand, it was proved that the business was better done by the Government than by the private companies, the Government would have beaten the companies in the fair field of competition and they could keep the ground without any question of purchase arising." I need not ask any one to say whether, during the fifteen or sixteen years since then, the company or the Government has succeeded. I think it is pretty obvious.

General WEBBER: May I interrupt on a point of order? The gentleman is speaking to something which is outside the paper that we are discussing. It is painful to me to sit and listen to statements on the question of the telephone industry in this country, every one of which I think I could refute. Therefore I ask as a point of order that the speaker, for whom I have the greatest respect, be asked to adhere to the subject of the paper.

Mr. CLAY: I think the title of the paper is a very wide one. It is "Before and After." I am dealing with the "Before." I submit that this is a case of a branch of the electric industry which is being hampered in a way in which it ought not to be hampered; and I think, in giving you certain information which cannot be at the disposal of many of the members, it may be useful and borne in mind in dealing with a similar problem connected with other branches of the profession.

I have told you that some years ago the Post Office allowed us to give our subscribers connection with the telegraph offices, so that they could deliver their messages. Now, within the last week or two, we are refused the facility for one of our exchanges. We were allowed to have it on payment of five guineas before; we are not allowed to have it on any terms now. Also, the facilities which subscribers enjoyed, and which some of them very much appreciated, of telegrams being transmitted to them, is now withdrawn from new subscribers. If the telephones were fully developed, surely telephones in connection with express messages would be a most valuable facility to everybody; but the companies are, of course, restricted from doing the business. The Post Office undertakes to do this business itself; but what does it do? It provides in London something like thirty-two places from which express messages can be sent. Under those conditions it is absolutely hopeless. If anybody wants to send an express message, he has to ascertain if the address he wants is within a mile of one of the post-offices. With regard to the veto of municipal authorities. In London, the County Council has the power to allow the company to place their wires underground. Some few years ago the company entered into an agreement with the County Council, and a resolution was passed by the Council enabling the company to place their wires underground. Nothing remained to be done but to put the terms into a formal agreement, and then the work would be completed. The

Mr. Clay.

County Council kept the company waiting a year, and when they submitted the formal agreement they put in two absolutely new clauses which had never been mentioned before. Consequently the company were unable to accept them, with the result that now there is comparatively only a small amount of underground work in the County of London. That is a result which I say is most prejudicial to the interests of the public. I would simply urge on the Institution the necessity of doing everything that is possible, by committees or otherwise, to protect the profession from the obstructions of municipal authorities. So far as competing with municipal authorities is concerned, if they will allow competition on fair terms, I have nothing to say. I will meet them with pleasure, provided there is a fair fight.

[*Communicated*]: Two examples from many of municipal obstruction many be interesting:—Underground wires exist from Hammersmith, etc., to north side of Holborn. Local authority refuse consent to connect exchange on other side, distance not more than 30 or 40 yards. Underground wires exist from Croydon, Sydenham, Bromley, Beckenham, Greenwich, etc., etc., to a point near St. George's Church, Borough, and from a point about 90 yards distant to the City. Authorities refuse to permit connection underground for this short distance except on prohibitive terms.

General C. E. WEBBER: This Institution, before the Parliamentary Committee sat which passed the Telephone Bill of 1899, did the very thing which the last speaker suggests they omitted to do. That Bill practically freed the telephone by enabling the Post Office to grant licences far freer and far more in the interests of the industry than anything I know of in connection with Electric Light Provisional Orders. It is the charter of all those who wish to extend the use of and to popularise the telephone industry in this country.

Mr. Gavey

Mr. J. GAVEY: The debate has, to my mind, rather digressed from the subject of the paper, and I would not intervene at this stage but that Mr. Clay has referred to what I must consider very ancient history in dealing with the telephone question. Perhaps unconsciously, he has done it in such a way as to lead members of the Institution to believe that the hampering regulations on the question of rates to which he refers exist at the present moment. Now trunk rates, whatever they may have been in the very early days of the industry, when we were all learning the business and before anybody knew how the thing was going to work out and what rates we could afford to charge, might have been high; but for many years the Telephone Company have had an absolutely free hand to charge exactly what they liked. As an illustration I may say that in many cases where the Post Office was in opposition to the Telephone Company in Provincial districts, they have gone to the Post Office subscribers and have provided, or offered to provide, wires and telephones free for considerable periods, in order to induce them to leave the Post Office service. I think in the face of that it is not right for a member to come here and say the Post Office has prevented the Company from charging reasonable rates, and that the Department has acted unfairly and has prevented the public from receiving a cheap and proper telephone service. Again, on certain other points it must

be borne in mind that in acting as the Post Office has, it is really protecting the rights of the Government under the Telegraph Acts. Those Acts were passed as the result of a public demand pressed on the Government, and they were carried by Parliament in response to those demands. Any subsequent action, whether the action of the Committee of the House of Commons, of the House of Commons, or of the Post Office itself, is the result, generally speaking, of public pressure. If Mr. Clay or members of the Institution will turn back to the minutes of evidence taken before the Committees of the House of Commons, they will find the general evidence was in favour of the telephones being taken over by the State; and, therefore, it is not with the view of oppressing a private company that the policy complained of has been initiated, but to meet the demands of the public. Mr. Gavey.

Col. R. E. CROMPTON: I, in common with everybody, have not only heard the paper, but have read it more than once with very great interest. I put this question to myself as a question that concerns every one who has the interest and honour of the electrical engineering profession at heart as an English Engineer. Why are we in England supposed to be—I say advisedly supposed to be—behind America and the Continent of Europe, in the development of electrical engineering? The question is a very vital one for this Institution, comprising as it does practically the whole of the members of our profession who are of any note or standing. On reading through the paper very carefully I found myself in full sympathy with the author. I agree with him, that it is not on account of our inefficiency as engineers that we are so behindhand; it is due to external causes. And one of those causes no doubt dates from the 1870 Tramways Act—an Act which fettered private enterprise and enabled municipalities to compete with private enterprise by funds raised on the security of the rates. The Tramways Act was the commencement of the curse that has hung over the country ever since. It is useless for Mr. Hammond to pose as a man with an inconveniently short memory: he forgets how, after the Electric Lighting Act came in force, municipal authorities obtained scores of Provisional Orders which have never been put in force. The municipal authorities never moved until private enterprise showed them how electric lighting could be made profitable in this country. There never would have been fourteen pence, not to say fourteen millions, put into it by the public bodies, if it had not been that a few of us got together private capital to show that we in England could do what they were already doing in America. It is well known to many what a hard task that was, how the few thousands that were got together in the early eighties were obtained by begging a few enterprising men to find money in order to show that electricity could be provided from house to house. There is no doubt that at that time the municipal authorities were our enemies. You can all remember their stock phrase, "We must have control of our own streets," was always put forward if we asked to do anything in the way of connecting up houses. The result was that the Electric Lighting Act of 1882 was passed, and the ridiculous B. of T. licences granted. In spite of all these things we started a few private enterprises for electrical distribution, and carried them on to such a Colonel Crompton.

Colonel Crompton.

pitch that public pressure was brought to bear on the Government, so that the Act was altered a few years later. As a prominent actor in those events, I think I can speak with some authority, and it appears to me that we are now exactly in the same position as regards the distribution of power on a large scale all over the country as we were then with the electric lighting. It is, as Mr. Hammond very rightly says, quite a question of whether, under English conditions of demand for power, it can be made to pay; but, if private enterprise proves this, will not the same thing be repeated? Will not the municipal authorities hang back until they see somebody else pulling the chestnuts out of the fire for them? That is what they are trying to do, and assuredly they will then do everything in their power to keep private capital from being put into these power concerns, just as they did in the early days of electric lighting. But, in spite of them, these power concerns will be brought forward, and in a few years the Local Authorities will go for Acts of Parliament to extend their districts, so that they may be able to work big power schemes themselves. I am quite convinced that that will be done, for history repeats itself. I have said enough on that point, but I wish to call attention to another very important one. There is no doubt that the impression prevails among the general public of England that we electrical engineers are to blame for the backwardness of electrical progress in this country—a most shameful and a most unmerited imputation, when you consider what we English electrical engineers have done. I claim for England a large share of the great things that have made electrical distribution possible. When we mention Dr. Hopkinson, and remember what has been done to introduce accumulators, which were first made and used on a large scale as an aid to central station work in this country and afterwards copied by other countries; when we know that it was England, through Willans, that introduced direct-acting high-pressure engines, which made possible all early stations in crowded areas, if I omit the multiphase transmission business, what have other countries done that we have not done in England? Who is to blame for the fact that our daily papers accept the rubbish that any American or German tout can stuff into them? There is no doubt that the English public, instructed by its non-technical Press, thoroughly believe that we English electrical engineers are woefully behindhand in electrical knowledge, and that it must look for aid from America or Germany for the hoped-for coming advances in electrical progress. I cannot help feeling that certain members of this Institution who speak at these meetings are to blame for this. How often do we hear men of scientific standing, although quite uninstructed in the real status and practical attainments of our English electrical manufacturers, hold forth to us on their return from their outings in America or on the Continent on our want of knowledge, and how necessary it is for us to go abroad to learn. This is pretty hard on those of us who have studied, from motives of the highest self-interest, the very problems on which they pass judgment so glibly. Surely we who have the same scientific attainments and add to it a much fuller knowledge of the practical conditions of our business and of the requirements of our

customers, and of the other factors which determine the choice of electrical machinery best suited to our Home and Colonial trade, are better able to judge of what is good for us than those who only glance at the matter during the course of their annual holiday. It would be well if such speakers, who by their remarks mislead the public and thereby do us English engineers more harm than good, would in future help forward the cause of electrical progress by dwelling more forcibly on the matters so clearly brought forward by the author of this paper and which no one doubts to be the principal cause of our want of progress. Colonel Crompt

Mr. H. HIRST (*communicated*): Like all previous speakers, I wish to congratulate Mr. Madgen on the happy choice of a paper which, judging from the discussion which has taken place so far, bids fair to be the starting-point of a crusade against legislative and other evils that impede the natural progress of cheap electric light supply throughout the country. It struck me, nobody had disputed we were behind other countries. It seems to be an admitted fact that municipal trading in electricity supply means splitting up the electricity supply of the country into small units, and is therefore an agent against cheap all-round supply throughout the country. Mr. Hi

Various causes have been given for this state of affairs. Mr. Madgen blames one-sided, grandmotherly legislation; another speaker suggests pandering too much to the democratic tendencies of the age; Mr. Swinton blames the construction of the Board of Trade; but has it occurred to anybody that a great portion of the wrong of which we complain lies with the electrical engineers themselves? These large schemes—these Power Bills—can only be carried out with some measure of success if electricity is generated and transmitted on principles that only a few years ago were pooh-poohed in this country by many of the leading electrical men. When one pointed to similar big enterprises on the Continent or in America, one was told within these very walls that multiphase transmission was not wanted unless it be for the purpose of utilising water-power which otherwise would run to waste. The idea that tramways with overhead wires would ever get a start in this country was ridiculed. We were going to have nothing unless we could get something better. Now, during the last year or two our eyes have been opened to the fact that if we do not wish to be left behind in the race we shall have to do as they did abroad, and now that the rush is coming on and the manufacturers of this country are scarcely ready to comply with the sudden demand, we forget our own shortcomings and are ready to kick at the Government. After all, the Government takes its keynote from the view of the most enlightened officials that we can put at its disposal, and if these officials see discord and disunion amongst the leading members of the profession on cardinal points, how can they be expected to anticipate the wants of the profession?

If only electrical engineers had known a few years ago what they wanted to-day, as they do now, I am sure means could have been found to alter the legislation, and I for one object to blame any particular Act for the present state of affairs. We all agree that the

Mr. Hirst

future industrial prosperity of this country depends to a very great extent on cheap electrical current. In fact, as the cry in the early fifties of the last century, around which Ministers formed their programmes, was for "cheap bread for the working man," so I should say the cry during the next fifty years, around which politicians will cluster their parties, can be very nearly expressed as "Electricity a penny per unit through the country," or thereabouts.

The success of every industry, with scarcely any exception, will depend on this cheap commodity. To achieve this, more than the alteration of one or two Tramway or Lighting Acts will have to be considered, and if Mr. Sellon's suggestion and hope that the outcome of this discussion may be an organised attempt to achieve something and to tell the Government what we want, becomes an accomplished fact, I trust such a committee may be chosen from this Institution as will treat the points in question from a large-minded point of view, that will bring wide knowledge to bear on the matter, and treat it in such a thorough and business-like manner, and form such proposals that the leading members of the Institution will agree to and submit to its rulings with confidence. If that can be done I am sure no Government will dare to defy the unanimous opinion of so powerful a scientific and industrial body as this Institution; but I rather think it would only too cheerfully take its guidance from us under such circumstances.

Mr. Baker.

Mr. C. A. BAKER (*communicated*): I am inclined to think that the point of view taken in this paper by the author is somewhat past date. Eight or ten years ago the conditions now pointed out most undoubtedly existed. The original mistake was obviously made by the Board of Trade in putting an entirely new enterprise in the hands of municipal authorities who dared not risk money borrowed on the security of the rates in experimental work. This necessitated a very slow development; in fact, development was not aimed at, but security, whilst other countries went ahead, and are now reaping the benefit of the early progress they were enabled to make. A little later the municipal authorities began to find that consulting electrical engineers were available, and these gentlemen have been largely employed in designing work and imposing conditions generally, again with a view to security rather than development. The only experimental development on a large scale that occurs to me at the moment as having been adopted in this country is the five-wire system at Manchester; the subsequent working of this system has not secured its popularity. Consulting engineers and manufacturers take different views as to the way work should be carried out, and no doubt the manufacturers of this country have suffered considerably by being placed so much under the control of consulting engineers through the instrumentality of municipal authorities.

At the present time there appears to be an abundance of work on hand. Many of the schemes which have been promoted by companies and received Parliamentary sanction are lying dormant, or the work in connection with them is proceeding very slowly; whilst, on the other hand, for several large schemes, where the work has been carried out, foreign machinery and material has had to be purchased in order to

get them to work in reasonable time. My conclusion, therefore, is that the Board of Trade and the Government Departments generally have sanctioned more schemes than our manufacturers are able to compete for. Mr. Baker.

Opposition to power schemes and other similar undertakings is often introduced not entirely through the local authorities or through the Board of Trade, or through Parliament, but owing to the keen competition amongst the numerous representatives of electrical engineers in all branches of the industry. Consequently, when a good scheme is proposed, it is not unfrequently met by an exactly similar scheme which is brought forward independently to cover practically the same area.

In connection with development, there is a point where our central station engineers still lag very much behind Continental and American practice. As long as twelve years ago, when I was acting as assistant engineer to the Italian Edison Company in Milan, we were using incandescent lamps consuming three watts per candle-power. It is still the practice in this country to use 4-watt lamps. A small calculation on these figures, allowing an ample sum for energy consumed by electric motors, arc lamps, etc., shows from the revenue received from electric supply during the last twelve months, that the public have paid considerably over a quarter of a million sterling in excess of the sum which should have been paid had the more efficient lamp been adopted. There are power schemes at the present time which would be glad of the offer of capital to this extent, and if, as is generally considered necessary, we have to make the best fight we can against gas-lighting undertakings, this point of the adoption of more efficient lamps should not be delayed.

Mr. A. B. CHATWOOD (*communicated*): It appears to me that the author of the paper, as well as the members to whose remarks I had the pleasure of listening, have evaded the point. If the paper deals with a subject worth our while to discuss—and I for one think it does—then let us face the problem before us and see whether some solution cannot be found. Mr. Chatwood.

Mr. Madgen gives two principal causes—silly legislation and official opposition. I think these two causes could have been given as one, since the second could not exist without the first. No one who was present and heard the course adopted by Southport—a course which cannot be considered other than idiotic—can for one moment doubt the existence of this second or subsidiary cause.

But is "silly legislation" a fundamental cause? I venture to think not. I, and probably all our members, will give the members of the Committee of the House which sat on these Bills credit for honesty, at any rate, if not for foresight and knowledge.

If we are to find the causes which have led to this silly legislation, let us compare our position with that of our colleagues in America when the industry in that country was just beginning its rapid advance. There we saw overhead wires, with their attendant risks to life, freely adopted, schemes which were ill-considered carried out on a large scale, the rights of property owners disregarded, and the "sacred" claims of vested interests set aside.

Mr. Chatwood.

We, on the contrary, have to face the natural consequences of the character which has been bred in us by the historical developments of our country during many centuries; we have to remember that our legislators hold life and property so sacred that they will not allow immature or experimental schemes to be carried out to the possible detriment or injury of the public.

Such, I think, is a fair review of the position. Our problem is not, therefore, that which Mr. Madgen puts, but is much more complex and difficult. The problem, it appears to me, is to settle first what we as electrical engineers desire, and, secondly, to induce Parliament, or a sufficient number of its members, to take our view.

We have been to blame, I think, in the past in that we have wrapped up our little bit of knowledge and experience and kept it in our offices, so that none should leak away without bringing its value to our coffers; and I am afraid that with some of us this knowledge and experience may have got a little rusty and out of date. Let us, therefore, do all we can in the future to teach the public, and more especially our legislators, that we can carry out our schemes without unduly risking life and without disregarding the rights of property, or, at any rate, without giving back with our right hand twice, nay, tenfold, as much as we take away with our left.

I conclude by suggesting that a committee be formed, not of members of this Institution only, but including one or two representatives of the legal profession, men who have had experience in Parliamentary procedure and have been in close relations with municipal officials, since, unless the views taken by municipal officials and others are represented, the researches of such a committee would be of little value.

Mr. Baillie.

Mr. G. H. BAILLIE (*communicated*): In connection with the criticisms we have heard of English legislature in electrical matters, it may be of interest to note how Italy has made more rapid progress than, perhaps, any other European country, under entirely different methods of procedure. There, the electric power laws are based on the principle that a municipality or a province should be allowed to do what it pleases on the property under its control. Thus, an electric lighting concession is granted solely and entirely by the municipality interested, and the Government merely reserves to itself the right of approving the details, which approval is such a formality, that, in the case of one electric lighting station, started by Mr. Woodhouse and myself, we had supplied light for three months before the ministerial decree arrived, giving us permission to start. In other interests than their own, however, municipalities have no power of obstruction, by reason of a useful clause in the electric light law, passed in 1894, which compels every proprietor, whether an individual or a municipality, to give way-leaves through his property to electrical mains. A power scheme, distributing over a large area, would depend on the Provincial Councils, who control the inter-urban roads; a municipality could not refuse permission to lay mains through its district, though it could refuse to allow any supply. In Italy, however, if the supply were good and cheap enough to make the inhabitants want it, they could practically compel the municipality to grant a concession for supply. Municipal supply

stations are very rare, probably because no town population will credit the municipal authorities with any desire but that of filling their own pockets; private enterprise, to a great extent German, has given Italy the enormous number of electric lighting stations now in operation, many of which supply villages so small and so poor, that a station running under Board of Trade rules would be financially impossible. Mr. Baillie.

I think a serious obstacle to the spread of electric light in England is the cost of house installations, which is so high as to be almost prohibitive to the poorer classes; in Italy, where the cost is less than half, even for good work, installations of 2, 3 and 4 lamps form a considerable part of a station's load. The system of wiring adopted is a much cheaper one, and would not be sanctioned in England; but still the houses do not burn, nor do the Insurance Companies fail.

Dr. Thompson's contention that water-power is no cheaper than steam-power, on account of the cost of the water-rights, does not hold in Italy, or I believe in Switzerland, as all rivers are Government property, and a concession costs only an annual sum of 3 francs per H.P. However, the capital cost of a water-power plant, and the fact that a long transmission is generally required, to bring the power where it is wanted, makes the advantage of water- over steam-power a very doubtful one, in the case of electric lighting with a small load factor, but a very decided one, in the case of an all-day power load.

Mr. EBENEZER HOWARD (*communicated*): Mr. Madgen in his paper dwelt upon the intimate connection between the development of electrical undertakings and the great housing problem. The only satisfactory way of dealing with the latter problem is to induce large bodies of work and of workers to establish themselves in new districts. This is what Mr. Madgen contends for. But this movement must be concerted; for if manufacturers leave congested centres in a concerted manner, they can secure for themselves and for their work-people far better results than by leaving singly. Mr. Madgen speaks of a comprehensive scheme for the generation of electrical energy as likely to attract manufacturers out of our crowded cities. But this system should be part of a still more comprehensive scheme. Factories need not only cheap motive power and light, but cheap sites, low rates, opportunities for necessary extensions, and railway facilities. They must be secured against interruptions of light and air; and above all must have, in contiguous or quickly-reached positions, healthy areas and healthy homes for their work-people. Start, then, a comprehensive system in which the supply of electrical energy for all purposes shall occupy no mean place. Plan out on some large and now scarcely-occupied estate a city which shall be abreast of modern ideas, and let the city grow to that plan as a house grows to the plan of its architect. Mr. Howard.

It should, surely, be possible to combine private and public enterprise, and to produce a great concrete result far higher than either could alone effect. It is practicable by private enterprise to purchase a large estate and to develop it in the public interest; to pay a fair rate of interest to those who find the necessary capital, and to give them besides an excellent security for their money. Then it is also practicable so to lay out the estate, and to offer such terms as to tenure and

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Mr. Howard. otherwise, that all classes will co-operate; and such a city will be followed, of course, by others, thus drawing the people out of our over-crowded cities and solving at the same time the problem of rural depopulation. This is the project of the Garden City Association—a project with which should be combined a comprehensive system of electricity supply.

Mr. Madgen. Mr. WM. L. MADGEN, in reply, said: So far as time will admit I shall endeavour to deal with the chief points which have been referred to by the various speakers.

In the first place I did not move a resolution, but I have no doubt that the almost unanimous opinion which has been expressed will have due weight with the Council, in considering the advisability of appointing a Committee to advise upon the most effective means of dealing with the serious obstacles with which the electrical industry has to contend.

Had I moved such a resolution I should have adopted Mr. Hammond's suggested amendment, that a Committee be formed to consider engineering matters connected with power supply, but for the fact that they will more usefully occupy the open discussions of the Institution.

The Wallsend power station on the Tyne for Newcastle and the north bank of the river down to North Shields, the County of Durham main power station at Gateshead, and the first main power station for the North Metropolitan district, are now rapidly approaching the completion of their first stage, so that the new era of electric supply has actually commenced, and that of small separate generating stations in such districts is passing away.

The matter we have been considering is no sectional question between one branch of the industry and another. It must be to the advantage of all that the applications of electrical science should be freed from the absurd restrictions imposed by the governing bodies of this country.

I am sorry that the question of Municipal Trading has been dragged into the debate. Apparently it would not have done for this paper, which, I am gratified to find, has practically the unanimous support of the members, with the exception of Mr. Hammond, to have gone forth without some objections being associated with it on behalf of such an apostle of Municipal Trading.

Mr. Hammond attributed the backwardness of our electrical industry to the cheapness of gas. Apart from the fact that we are not talking of lighting alone, but also of *power* and of *traction*, can such an argument be regarded as serious when it is well known that the cost of gas is mainly governed by the price of coal, and in this country the price of coal is common to both forms of illuminant?

Dr. Silvanus Thompson alluded to the interesting question of the economic limit of size of a power station. As you may suppose, such matters have been very fully considered by those of us who were actively concerned with the Power Bills of last session, and a large amount of information was gathered together. It was of course impossible for me to compress this material within the limits of my

paper. I felt in preparing it that my first duty to the Institution was to indicate the steps which should be taken to remove the obstacles to these developments which have already been amply demonstrated in practice elsewhere. Mr. Madgen.

Some five years ago the critical limit, beyond which it would be as well to have two stations as one of larger size, was placed by a prominent writer at about 5,000 H.P., but now that single steam-alternators equal this figure it is seen to be absurdly low.

There is, as a rule, no gain in the boilers after a power-station has reached a few thousand horse-power capacity, and as station size increases the boilers are not made larger, but increased in number. With engines there is a continuing advantage as the size increases, both in efficiency, space occupied, and weight per horse-power; and, as the largest sizes so far used for electrical purposes are greatly exceeded by those of a similar type used in marine practice, special experimental work is not yet occasioned by increase in size, and the cost per horse-power continues to go down as the size increases. Alternator design is now so well understood that untried sizes can be built with confidence, but there is said to be no economy in first cost per horse-power of unusual sizes, as the special designs and construction outweigh the saving in material and workmanship.

An example of the smaller economies effected in construction is that one crane will serve an engine-room containing ten generators as well as one containing five.

However large the station, there is still a gain in the capital cost per horse-power installed due to concentration, as it is much cheaper to erect and to house duplicate plant at one point than to construct the equivalent at several points. As capital charges are the largest item in the cost of electrical energy, the most important saving due to centralisation is the greatly reduced capital cost per horse-power installed.

In regard to running expenses, even if the size has become so great that the concentration allows no increase in the size of units of generating plant, the duplication allows many economies of this nature that could not be attempted with a smaller equipment. This is owing to the fact that the complexity of these economies does not increase with their increased size, while the saving is proportional to the size. Many details, such as oil-circulating equipment, coal and ash-handling machinery mechanical draft, economisers, &c., are thus affected. The larger the station, also, the greater is the differentiation of labour, and in consequence the greater is the efficiency of that labour.

It is now regarded as a truism that the greater the centralisation of the power plant the better is the load factor. In a lighting system the peak of the load does not coincide in residential and business districts. In a traction system, pleasure resort lines may have their peak at one time and the lines serving business districts at another. Combined lighting, power distribution, and traction systems gain still more by the improvement in load factor due to the combination of different loads.

Thus it appears that increase in size causes a continued increase in economy, so far as the power-station itself is concerned. This increase undoubtedly grows smaller and smaller as the size continues to increase,

Mr. Madgen. but never reaches zero. At a certain point this gain is met by the disadvantage of long feeders, but with high-tension transmission it is not reached until the district is a very large one, sufficiently large in areas of a suitable character for stations of a power hitherto unheard of.

The above remarks are in part a paraphrase of some interesting notes which appeared in the *Electrical World* of New York, August 13, 1899.

Other considerations which come into the question may be indicated best by extracts from letters received in June of last year from our friend Mr. Gisbert Kapp, of Berlin, from Mr. Edgar, President of the Edison Electric Illuminating Company, of Boston, and from Mr. R. S. Hale, of Boston.

Mr. Kapp wrote : "The principles upon which you have been working have long ago been recognised as sound in Germany. In Silesia there is a steam-driven station supplying a large district with 10,000-volt 3-phase current. The Rheinfelden station, as you know, supplies into Switzerland and Germany over wide districts, and its power is fully taken up. In Berlin the old system of having town stations each for a limited area is being supplemented by outside stations and long distance transmission. In Schönweide, to the east of Berlin, there is a large 6,800-volt 3-phase station which supplies various parishes. A new station is now in construction in the north, and another is projected for the west. In all there are now on order eight steam 3-phasers of 3,000 kw. each. One parish south-east of Berlin, for which I am consulting engineer, has an offer for current from the large eastern station at low prices. I am just working out the plans for a municipal station,[1] and as far as I have been able to see at present the home-made current will come more expensive than the current from the large eastern station."

Mr. Edgar said : "This Company has had, for the past ten years, its principal lighting station upon the water front near the centre of distribution. A year or two ago it was foreseen that the facilities of this station would be completely required for the winter of 1900. It therefore became an important question as to whether this station should be enlarged or a station laid down in some other section of the city. After considering this question quite thoroughly, it was decided by all concerned that the proper action to take was to enlarge the existing station, and we are now building upon the same premises, and adjoining the old station, a power house of a capacity equal to double that of the old station. The entire plant is so designed that for all practical purposes it is one station ; but at the same time, as a matter of precaution against steam-pipe explosions or troubles of that character, both the engine and boiler rooms are divided into two separate and distinct risks, while the switch-board is located in a structure entirely separate from the remainder of the station. The old station had a capacity of 6,500 H.P., while the new one is laid out for 15,600, making a grand

[1] Since this discussion I have been informed by Mr. Kapp that upon his advice the idea of the separate municipal generating station has been abandoned, and the current is now supplied direct from the main power station he refers to.

Mr. Madgen.

total of something over 20,000 H.P. when completed. We have therefore had to meet the same problem which you raise in your letter, and have decided it as I have described—viz., to locate on one premises practically all of the generating facilities of the Company, subdividing them into two or more fire risks by substantial walls, but getting all the benefit of concentration in the keeping down of operating expenses."

Mr. Hale wrote: "I should say that the general idea here was that stations of 50,000 to 100,000 H.P. are more economical than smaller stations. My own investigations have shown that boiler plants of 3,000 to 4,000 H.P. had reached the point where no further economy was to be gained by increasing the size, but as regards engines, the use of engines of 5,000 H.P. makes it necessary to have very much larger stations so as to have a reserve unit without having too great a percentage of the capital lying idle. If we go to engines of 10,000 or 20,000 H.P. each, of course that will mean still larger stations, and, judging from the increase in size of engines in the last five or ten years, I should think it very probable that a 5,000 H.P. engine may be considered a small-sized unit before long."

Before the year is out fuller particulars will be available of the development of several steam-driven electric power stations of ten to twenty thousand horse power which will further demonstrate the folly of continuing in this country the era of a wasteful little toy station for each township.

One of the finest examples is that of the Metropolitan Street Railway Company of New York. In the relatively small area of twenty square miles this company has 217 miles of tramway track, 82 miles of which are now worked electrically, and much of the rest, including the celebrated Broadway cable line, is being "converted." The generating plant has been concentrated in a power station on the water front at 96th Street, and comprises no less than 45,000 kw., the large 3-phase plant units being of 3,500 kw. each. The electro-pneumatic switchgear is divided up in a manner analogous to a modern organ, and the required "tune" can be played on it, so to speak, from a central keyboard. There are many other points of great interest in this power station, and by the courtesy of the British Thomson-Houston Company I am enabled to put in—for the library—copy of a complete description with illustrations and dimensioned drawings.

The controversies between the adherents of theory and of practice in this Institution, and personal questions of priority of disclosure, have become a very stale convention to many of us, and there is a general feeling, I believe, that we might well have less of them. I am sadly conscious that any sympathy I may have had for Professor Ayrton on such occasions has been dissipated this evening. It appears that he has been among the back numbers, and has found that he said something or other in 1879 which we may, or may not, recognise as a broad claim to modern developments in electrical supply over large areas. Professor Ayrton then said that it cannot be the fault of Parliament or of the Local Authorities that the Metropolitan Railway trains are not run by electricity. True, but what are the circumstances of the Metropolitan Railway? It is in itself a monument to private enterprise, but

Mr. Madgen. the net earnings are very moderate, relatively to the public service it affords, and it is a grave question of finance whether the additional capital cost of making a radical change in the method of working would be an advantage to the proprietors. Moreover some three or four main lines have running powers over part of the circle, and arrangements in regard to them have to be considered. We should all like to see the change brought about, but it is no discredit to private enterprise that it should take heed what it is doing.

Professor Ayrton mentioned that on behalf of a local authority he had approached a large company to ask upon what terms it would supply in bulk to the extent of 500 H.P. The reply was 3d. per unit, and under the circumstances I am not at all surprised. Why should any one with a power station, selling retail over a large area, go out of his way to supply at a special rate to one wholesale consumer with such a small demand?

There appeared to be some question as to whether Mr. Clay was in order in bringing in the telephone question. I am aware that the company is not very popular to-day, and any whip appears to be good enough to scourge them with, but I do not suppose that those of us who are unfamiliar with telephone work can realise the difficulties under which they have been carrying on the service. The wonder is not so much that it has been done indifferent well, as that it has been done at all. Practically the whole of their wires are overhead, they have to get wayleaves where they can, and are liable to be victimised at every turn. Mr. Gavey reproached the telephone company with having resorted to the device of offering a free service in certain cases in order to compete with the Post Office. It is the Government which is responsible for any expedients to which the company may have been driven in order to preserve their business. It is the Government which is mainly responsible for the present chaotic condition of telephone work.

It is a great satisfaction to me that Colonel Crompton has appreciated the intention of this paper. After the E. L. Amendment Act of 1888 was passed it was due to his initiative that pioneer supply stations, which have served as an incentive to much that since has been done, were equipped at Kensington, Northampton, Southampton, Hove, and elsewhere, and he affords us an example of what can be done for an industry by individual enterprise.

My thanks are also due to the several other representative members who have supported the movement in favour of the Institution taking steps for the removal of the legislative and other difficulties which are retarding so very seriously the progress of electrical work in this country.

Dr. Silvanus Thompson concluded his remarks with a parable, and if you will allow me I shall do the same. In most domestic circles—certainly in the one with which I am best acquainted—there is a small member who wishes to know why you leave the house reasonably early, and why you do not return until sometimes unreasonably late. It is usual to tell this small person that it is for the purpose of bringing her bread and butter. Well, this is a bread-and-butter question. It

Mr. Madgen

is a question affecting the interests of this Institution as a whole. Surely it cannot be in the better interest of any consulting engineer, however "municipal" he may be, that the industry should be "held up" as it now is. If the means of progress are enfranchised, surely it will not be any impediment to municipal enterprise in the same direction.

It is to our interest to see to it that these legislative restrictions are removed. And I may put it higher than that—it is our duty. Members of Parliament, County Councillors, and other elected persons have at length discovered that electric traction is a means of relieving the congestion of population. Some of them, indeed, are beginning to quarrel as to which of them first suggested it! Personally I believe that electrical-power distribution, by assisting the migration of industries into more open country, can do even more to relieve overcrowding. If this be so, if the greatest evil of our time, the overcrowding and the unhappy condition in which the working classes are living, can be alleviated by means of electrical power distribution and traction on a comprehensive scale, clearly then it is our duty to see that the path is cleared for us to carry out our mission.

The President

The PRESIDENT: Gentlemen,—May I ask you to give a hearty vote of thanks to Mr. Madgen for his interesting paper?

Carried with acclamation.

The PRESIDENT announced that the scrutineers reported the following to have been duly elected:—

Members:

Major Andrew Bain, E.E., R.E.	James Ferguson.

Associates:

Robert Marshall Carr.	William Harold Spencer.
Alexander Charles Cramb.	Christopher Wilson.
Richard Bertram Leach.	Ernest Wilson.
Henry James Nisbett.	

Students:

William J. Daly.	Edward Garfield Taylor.
Thomas Abba Davies.	Norman Thirlby.
Walter William Symper.	Francis Edward Wilkinson.

DUBLIN LOCAL SECTION.

(Abstract of Paper read at Meeting of June 14th, 1900.)

THE DUBLIN CORPORATION ELECTRIC LIGHT SCHEME.

By ROBERT HAMMOND, Member.

Mr. Hammond first laid down the general principles that must be fulfilled by any such Corporation scheme. These he enumerated as follows: (I.) The service must be uniformly excellent. (II.) It must be cheap. (III.) It must be satisfactory to the ratepayer—(*a*) by not requiring too large a capital expenditure, (*b*) by utilising the existing plant as far as possible, (*c*) by disturbing the streets as seldom as possible, (*d*) by providing a good system of street lighting.

The scheme he proposes fulfils all these conditions: (I.) He provides a uniformly excellent service—(*a*) by the generating works, and (*b*) by the system of feeding he specifies.

(*a*) The generating station. He proposes to provide Corliss gear with slow-speed plant, because he considers this tends to steadiness of pressure and efficiency of engines when plant is on a large scale. He has had a considerable experience of both systems under varying conditions, and that is the result of it. He considers that the plant should be specially designed for the purpose in hand, and not a ready-made plant.

(*b*) The distributing system. There are to be three triphase trunk mains connecting the Pigeon House generating station with a central distributing station at the present generating station in Fleet Street. Each main is to consist of three conductors, each of 0·15 section, which at 5,000 volts will transmit 1,300 kilowatts in each cable. The works are intended in the first place to generate 2,600 kilowatts, and the cables will carry 50 per cent. more, so as to provide for unforeseen contingencies, such as a breakdown. The cables are to be laid in iron troughs filled in with bitumen. From Fleet Street the current is to be distributed (still at 5,000 volts) to 19 substations scattered throughout Dublin. In these substations the pressure is to be reduced by transformers and distributed to consumers at 240 volts. The network from each of these substations is to be ordinarily unconnected with its neighbours, but provision will be made for interconnections when required. This independence of the networks is desirable in order to facilitate the location of faults, etc. It is designed that the loss on the cable to Fleet Street at top load shall be about 5 per cent., and on the longest feeder to a substation 1 per cent. at most.

(II.) The service must be cheap. This is secured by (1) as good a a load-factor as possible, (2) a large output, (3) raw materials, coal, water, etc., as cheap as possible, (4) first-class plant.

(1) The load-factor is not under the control of the suppliers, except to the extent that they cater for power distribution. This is one reason for working a triphase system of rather low periodicity. In the distribution of electrical energy for both power and light from the same mains the sectional area must be such as to keep the losses fairly low; but there is no real difficulty in working a power supply system on the electric light mains, as for example at Frankfort. Polyphase systems of distribution are a success on the Continent, as for example at Mainz, Manheim, and Strasburg. In Strasburg, for example, there is a three-phase system of 3,000 volts transformed to 100. There 900 k.w. are transformed to continuous current for the tramcar system. The same should be done in Dublin. In Strasburg they produced 1,300,000 units for power, 1,190,000 units for the trams, and 230,000 units utilised in three-phase motors and transformed on the consumers' premises. They particularly liked the three-phase motors as being very convenient for power production under a great variety of circumstances. It has been doubted whether it is possible to balance the voltage on the three wires of a triphase system satisfactorily when used for electric lighting; but it has been proved by actual experience that there is no serious difficulty in doing this. With regard to power, it is to be hoped that in Dublin, as on the Continent, there will grow up a large demand for power, and so produce a satisfactory load-factor.

(2) A large enough output is practically certain from experience in other cities where a satisfactory system of electric lighting has been installed.

(3) Command of cheap coal and water is secured by going to the Pigeon House, where coal can be delivered from shipboard and water for condensing pumped from the sea. In addition to these advantages the Pigeon House provides land cheap, room for extensions, no troublesome neighbours, and a distance from Dublin of only three miles.

(4) The plant to be installed is carefully specified to be of first-class design. It is to be divided into two sets of 500 k.w. and two of 1,000 k.w., and alternative tenders are asked for both compound and triple expansion engines. It is desirable to have some comparatively small units for work during the times of small demand. The specification of the engines and dynamos is drawn up in terms of steam consumption per kilowatt. The steam is to be superheated about 150 or 160 degrees. A 26-inch vacuum (with allowance for low barometer) will be demanded. It is required that the consumption shall not exceed 19 lbs. of steam per k.w. in the compound, nor 17 lbs. per k.w. in the triple engines, which works out as 12·11 I.H.P. for the double and 10·84 I.H.P. for the triple expansion engines at an 85 per cent. all-round efficiency. The transformer loss need not be great, if we are to judge by experience elsewhere. For example, at Leeds, with a high-pressure alternating system, the average cost per unit in 1898 was 1·29d. generated and distributed to consumers, which may be compared with Bradford, which has a low-pressure supply for the same period at 1·43d. per unit. Of 29 works which produce at a lower cost than 2d. per unit, 14 are alternating and 15 continuous current, so that there is no difficulty about transformer losses. He considered that it should be

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possible to generate at 1·5d. per unit in Dublin. This would be at 3·37d. with repayment, and if they charged 4·5d. for private and 2d. for public lighting this would provide 3·42d., and thus leave a little for contingencies.

(III.) He arranged to satisfy the ratepayers in the three ways enumerated.

(*a*) By not embarking on too large a capital expenditure. This was an important reason why he designed this triphase system. Low-pressure continuous-current systems are too expensive in feeders. By going to the Pigeon House, as already explained, a small capital expenditure on ground was secured.

(*b*) He proposed to utilise the existing alternating-current system by transformers at Fleet Street. The frequency would be reduced, but otherwise the present network, the five transformer stations, etc., would be utilised.

(*c*) To prevent disturbance of the streets he proposed to lay down immediately sufficiently large mains to supply extension for several years to come, and to lay the mains in such a sound and secure way that there was practically no danger of faults occurring in the streets necessitating their being opened for repairs.

(*d*) To provide efficient public lighting he proposed substituting for the present arrangements a system of 500 arc lamps, utilising the existing culverts where possible. These public arc lamps are to be on special circuits separate from the other power and light distributing system.

In conclusion Mr. Hammond defended the general principle of a three-wire system of distribution. If out of balance to the extent of 50 per cent., this would not produce a greater difference of voltage than 100 volts, which was only 2 per cent. on the 5,000 volts they were installing. The Midland Company, one of the largest schemes recently proposed, was providing a balanced three-phase system, and he might say that three-phase systems were almost universally employed now with success.

Mr Porte. Mr. A. E. Porte congratulated the Section on getting Mr. Hammond to come over and unfold his scheme. He raised questions as to the difficulty of getting good foundations at the Pigeon House, and quoted some results of borings. He thought it would be interesting to hear how this difficulty was to be met. If the strata are as described, there would appear to be danger of the clay being worked out by the action of the tides.

He criticised the provision for motor load, which he thought was very inadequate. He would have been glad to have seen 600 to 800 H.P. provided for this purpose. In Cork, with a population about one-third that of Dublin, there was, eighteen months after the opening of the station, a motor-load of 400 H.P.

He desired to know why single-phase motors were not more used at present on the existing supply. He considered the provision of 500 arcs as greatly in excess of what could be required. He agreed as to the desirability of specifying 1,000 k.w. units driven by slow-speed

Corliss compound engines, but wished to know what efficiency was expected from the triple engines on a low load. Mr. Porte.

Mr. R. HUMPHRIES spoke as to the effect of the voltage of a three-phase distribution system when a large inductive load such as an induction motor was thrown in and out of circuit. He had had experience on the Dublin Southern Tramways with three-phase transmission, and knew the variation to be considerable that takes place on the terminals at the far end of a cable. The General Electric Company of America had developed a system known as the Monocyclic System for just this purpose, to keep the motors and lamps on circuit separated from one another. The conditions were altogether different to throwing continuous-current motors in and out of circuit. The makers were guaranteeing a maximum variation in voltage with change of load, but did this refer to an inductive load? Mr. Humphries.

Referring to Mr. Hammond's wish for a large load-factor, this was exactly what was offered by a combined traction and lighting system. Notwithstanding Mr. Hammond's reference for plant made to order, he preferred the system of having standard plant, as it could be produced of good type much cheaper than special plant, and the fact that it was standardised proved that the machinery had well withstood its tests.

Mr. C. P. C. CUMMINS also expressed a decided opinion in favour of specifying plant of standard pattern. He had had experience in America of the value of standard patterns, and had been strongly impressed with their value. He regretted that Mr. Hammond had been unable to give some of the figures which so staggered him, when considering other systems. Mr. Cummins.

Mr. S. A. MALPAS asked whether any difficulty was experienced in getting a sufficient number of competitive tenders, as other efficiencies were introduced such as air-pump and condenser efficiencies, and many of the smaller manufacturers would decline to tender rather than take the responsibility. Mr. Malpas

Mr. SAYER questioned the facilities at the Pigeon House for delivery of coal, as large vessels could not there come alongside. He also desired information as to the facilities for obtaining fresh water for the boilers. Mr. Sayer.

Mr. J. R. SYKES reiterated Mr. Sayer's doubt as to the cheap delivery of coal, and further inquired whether the roadway was sufficiently well constructed to carry heavy machinery, and asked if a carrying company had not raised difficulties as to the delivery of plant. Mr. Sykes.

Professor G. F. FITZGERALD (*Chairman*), in calling on Mr. Hammond to reply, congratulated the Section on having had this interesting and valuable communication brought before it, and particularly thanked Mr. Hammond for the very great amount of trouble he had taken in giving them this account of the proposed Dublin supply. He expressed a preference for clothes made to order rather than for ready-made clothes, and rather sympathised with Mr. Hammond's views as to the desirability of designing plant for the special purpose they were to fulfil. He called attention to the value of the work done by scientific investigation, in that the two quantities most accurately and easily Professor Fitzgerald.

Professor Fitzgerald.

measured were water and electric energy; the oldest and the newest of measured things—matter and energy. He expressed a hope that a three-phase system would be introduced, because the educational value of such a complicated system, and one whose working was so difficult to understand, would be very great, and it would emphasise in Dublin the necessity for a sound scientific basis for the education of engineers.

Mr. Hammond.

Mr. HAMMOND replied that as regards the foundation the Corporation were acting under the very best advice, and that the citizens might be confident that no structures or engines would be erected except on perfectly secure foundations, and that there was no serious reason to think that the expense of foundations would be excessive. In answer to the objection that the installation was not big enough, he could only hope that it would be much bigger, and that while the Tramway Company desired to obtain the supply of power for lighting Dublin, the Corporation were desirous of obtaining the supply of power to the tramways. One of the reasons why single-phase motors were not more used in Dublin was on account of the high frequency of the present supply; with the lower frequency proposed he expected a considerable development of their use. He did not think they were proposing too great a number of arc lights for a city like Dublin, and the power involved was so insignificant that it was undesirable to restrict the number below what might be of service. There had been no difficulty at all in getting contractors to undertake to deliver heavy goods at the Pigeon House, which, notwithstanding the various criticisms was, in every way suitable for an installation, being nearer the distributing area than most new installations in large cities, which were gradually being moved outside the cities for the sake of space and other facilities. In conclusion he expressed the pleasure it had given him to make this communication to the Dublin Section.

A cordial vote of thanks to Mr. Hammond for his exceedingly interesting paper was afterwards carried by acclamation.

NEWCASTLE LOCAL SECTION.

Paper read at Meeting of Section, January 14, 1901.

ELECTRICALLY-DRIVEN MACHINE TOOLS, AND THEIR ADVANTAGES FOR USE IN ENGINEERING WORKSHOPS.

By G. RALPH, Associate-Member.

Although the subject chosen is of great importance, particularly in great engineering centres like Newcastle-on-Tyne, the author feels that an apology is due to the Local Section of the Institution of Electrical Engineers for the *character* of the paper, since there is little or nothing in it which is not already well known to many.

Owing, however, to the list of papers for the Session being somewhat scanty, it was necessary for some one to make an offer, and the author hopes that his attempt may be the means of inducing others to produce something better.

Before describing the methods of gearing and application of electric motors to various purposes in the engineering shops, it may be well to draw attention to some of the points which appeal most strongly to a works manager in favour of electrical driving.

One of the foremost of these is the ease with which machines may be so arranged with reference to one another as to facilitate the "following on" of work from one tool to another, without an excessive amount of handling, either by manual labour or by overhead cranes. Where all the machine tools are driven from line shafting, they must follow a more or less rigid arrangement in lines parallel to the shafting, which is not by any means the most convenient way in many cases, although this arrangement has become so general from years of use that it does not at once strike the casual observer that it is inconvenient.

Many shops are built in two bays, only one of which is served by overhead travelling cranes, while the main shafting is erected in the other bay, and thus most of the machines are collected together in or near that bay. Where the height

of the shops is limited, as is often the case when the building has two or more stories, it is impracticable, in many instances, to place machines on the far side of the bay served by the travelling cranes, owing to the difficulty of getting belts across from the line shafting. The author is, of course, aware that this difficulty does not exist in large shops where there is plenty of head room, as a second line shaft can be erected below the traveller gantry on the walls or columns. But one cannot make more head room if it does not exist, and has to make the best of circumstances. In such cases the application of electric motors to individual machines proves of great advantage.

Taking a case which came under the author's notice some time ago as an instance. It used to be necessary to transport all the heavy magnet-castings from the planing-machines at one end of the shop by hand travelling cranes, to a large radial drill at the opposite end. After drilling, these had to be brought back again to the boring machines near the place where they started from. It was decided to move the radial drill from that position to a point about midway between the planing and boring machines on the opposite side of the bay. These large masses of material now only have to be lifted across to the other side of the bay for drilling, and zig-zag back again for boring, instead of being twice carried almost the full length of the shop. This instance gives some idea of the convenience of being able to group machines together in the best manner. It would have been impracticable to drive this radial drill from the line shafting in its new position in this particular case. Several other tools were moved to new positions from the same considerations, and this resulted in much less handling of material and in greater output. Those of us who are engaged in the manufacture of heavy machinery will know that the proper supply and following on of work from one machine to another is second only in importance to the output of the machine tools, from a commercial point of view. As it has been very aptly put in an article by Mr. Hutton, in one of the engineering magazines, "the productive shop, being a tool, can be regarded as a *machine*, to be designed for a specific purpose. In this design the special tool is the *cutting edge*, while the internal system of transportation, whereby work is brought and presented to

the special tools, may be regarded as the *feed motions* of the machine."

Another great advantage of applying separate motors to individual tools is the ease with which the speed of the machine can be varied without the necessity of shifting belts on the cone pulleys. The average machine-hand will, in most cases, not take the trouble to shift his belt to suit the size of work unless closely and constantly watched by the foreman; but give him a small regulating switch close to his hand, when he has only to give a knob a quarter turn to increase his speed by 25 or 50 per cent., and he will do it.

Many motors for machine tool driving are so constructed that the speed may be increased to double the normal speed simply by varying the exciting current in the shunt winding, which is, of course, much more efficient than inserting resistance in the main circuit for varying the speed. If, in addition to this, the motor-armature be double-wound with two commutators, a variation of 1:4 or more can be obtained, since, by connecting the windings in series or parallel, the speed can be halved or doubled as desired. Also the graduations of speed can be made much finer than by step cones and back gear, so that it is possible to get the correct speed for almost any variety of work put on the machine. It is quite a common thing to have 15 or 20 steps on the regulating switch, and an equivalent number of different speeds. While speaking of this matter, it may be mentioned that machine tools might in many cases be much improved in this respect for ordinary belt driving; the graduations of speed on many lathes, &c., are not satisfactory, and the machine tool makers seem to have paid very little attention to this point in the past, although it is receiving more now.

The possibility of a wide range of speed is, in the author's opinion, a very strong argument in favour of continuous current motors in engineering works as against alternating current motors. With single phase motors, whether synchronous or self-starting induction motors, it is not practicable to vary the speed, since both classes depend more or less on running in step with the generating plant. With two- and three-phase motors the same objection exists, though not in the same degree. The speed can be varied by special devices, but the author understands that when

running below their normal speed they are very inefficient. He has no actual experience with them, and it will be very interesting probably to most of us if anyone can give further information on this point in the discussion. The author regrets that he has to confess his ignorance on this subject; but, according to President Perry's address, many other engineers are in the same lamentable state. This is not a paper on the relative merits of direct and alternating current supply for motors; but the question of speed variation is one which should not be lost sight of by engineers when debating which system to install in their workshops or shipyards.

Since writing this, the author has read the excellent paper given before the Manchester Section of the Institution, by Mr. H. A. Earle, on the relative advantages of direct and alternating current distribution, which states in a much better and clearer form than has hitherto been published the points for and against each system.

Another advantage of applying separate motors to individual machines is found when it becomes necessary to work overtime in the shops. It may so happen—and often does in the author's experience—that, although the shops in general are not overcrowded with work, a tremendous amount may have accumulated for some particular class or group of machines. It is obviously very uneconomical to run the whole of the shafting, belting, main engines and boilers for the sake of one or two machines till seven or nine o'clock every evening, but yet the work must be got through. One cannot purchase new lathes or boring machines at a few days' notice—in this country, at any rate—nor would it be advisable or profitable to do so, if the large increase in this particular class of work is merely temporary, as is generally the case. But if the works manager be fortunate enough to have these machines electrically driven by their own special motors, his difficulty is solved, for it is possible to work any amount of overtime without serious increase of establishment charges. More fortunate is he still if a supply of energy be available from a storage battery or from the town mains. It is then possible to run night and day by putting a double shift of men on, until the accumulation of work at these machines has been got rid of. It is even possible to take advantage of

a double shift on machines which are driven from the main shafting, as a rule, by putting down a temporary motor on the floor to drive the machine at night, while through the day it may be driven either from this motor or from the shafting as before.

Just now, at the works with which the author is connected, there is a large amount of work for which only two or three machines in the shops are well adapted, so two of these have been running night and day for some months past. One is a horizontal boring mill, which is always driven by its own motor; the other is a large face-plate lathe of the ordinary pattern, usually driven by belt from the shafting. At night, the belt is left on the loose pulley of its counter-shaft, and a belt is slipped on to the fast pulley from a portable motor—with spur reduction gearing attached—which is spiked down to the floor behind the lathe. The starting and regulating switches are temporarily fixed on the front of the lathe headstock, convenient to the man's hand. These machines and the necessary lights are run from the storage battery at present. Probably, before long, the continuous-current supply from the Newcastle Electric Supply Company will be available for this or any other purpose. Again, in the event of an urgent repair or break-down, work must sometimes go on without intermission, and in such cases it is very convenient to be able to put down a motor at an hour's notice, to run any machine all night. A few weeks ago, a motor at one of the shipyards on the Tyne got accidentally damaged by water or otherwise. The field-magnet coils were brought to the works at 4 p.m. to be rewound, and were wanted as early as possible the next morning. Shortly after 5 p.m. the magnet-winding lathe was belted to a motor and ready for running all night, and the repairs effected by 6 o'clock next morning.

It often happens that contracts are taken for manufacturing machinery of a larger size than any of the regular tools in the shops are capable of dealing with. It is then a case of rigging up special appliances, and carrying them to the castings to be operated on. For instance, some large steel rings for the yokes of multipolar dynamos were far too large for any of the lathes or boring machines to deal with. So a boring bar was made, with standards easily adjustable for height; the magnet-rings were fixed to the slide-rails of the

testing-bed, and the boring bar driven by a motor, put down temporarily for the purpose. The work was very satisfactorily performed, which otherwise would have had to be sent to some other engineering works where much larger machine tools were available.

It is now considered much the better plan in works where very large dynamos and alternators are constructed, to employ portable electrically driven tools for slotting, drilling, and planing the large castings necessary. These portable tools are grouped about the casting, and, in many cases, two or more can be operating simultaneously. For instance, one machine may be planing or slotting the face of the half ring, while another is drilling holes through the body for bolting the pole pieces on.. Portable tools of this description are employed in practically all the large electrical works at home and abroad. There can be no question that this is the proper method of dealing with large castings.

The question as to whether every machine tool should have its own separate motor, or whether groups of machines should be driven from a line shaft to which one large motor is belted, has been frequently discussed, and it is to be hoped that views on the subject will be expressed to-night. There is much to be said for both systems. In the author's opinion no hard and fast rule can be laid down ; each case must be dealt with on its merits, as the circumstances vary so much, especially when converting an old shop to electric driving. As a general rule, it would appear that all large tools demanding, say, 2 H.P. and upwards, may very suitably have their own motors. The loss of power in driving long lengths of shafting and belts and countershafting is a very large proportion of the total power developed in most cases. The author is aware that this statement is often rather pooh-poohed by mechanical engineers, and said to be exaggerated. But it is a very easy matter to prove our statements. The readiness with which the power used can be measured (when electricity is the motive power), for all the varying conditions under which workshops run is in itself an advantage. In a paper read before the American Society of Mechanical Engineers, Professor Benjamin stated that in six shops taken at random, where heavy machine work was done, an average of 62 per cent. of the power produced was

used in driving the shafting. In one case the loss was 80 per cent.

The author has made some tests recently, the results of which are given below. A length of 100 ft. of 2½ in. diam. shafting, running at 150 revolutions per minute, to which twenty-four machines were belted, took to drive it light, 45 per cent. of the power necessary when all the machines were in use. In another case, the power taken to run the shafting and belting on the four floors of a works was 56 per cent. of the average power required when the shops were in full swing. The motor used for driving was belted to the centre of the shafting on the first floor. On the ground and first floors the shafting is 2½ in. diam., and a total length of 240 feet, running at about 130 revolutions per minute. To this shafting are belted 71 machines of all classes, the ground floor chiefly lathes and planers, and the first floor light brass-finishing machines chiefly. There is about 100 feet of 2 in. shafting on the second floor, running at 150 revolutions per minute, driving twenty-one machines, chiefly for brass-finishing work and magnet-winding; and a short length of 1½ in. shafting on the third floor. The loss of power in the line shafting and belting is going on continuously during working hours; whereas, with motors to individual tools, whatever loss there may be in the leads, motors, and reduction gearing, is not continuous, for the motors are stopped when the machine is not at work, through changing work, or setting fresh tools, &c. There is thus a further gain in this respect.

With regard to the total h.p. of motors installed, and the average power used, it is in most cases possible to put down a much greater collective h.p. in motors than the power station is capable of supplying, for it seldom happens that the whole of the motors are called upon to develop their full power simultaneously. The ratio seems to vary within pretty wide limits. It is stated that in the Baldwin Locomotive Works only 1,300 h.p. serves about 3,100 h.p. of motors, a ratio of 1 : 2·4. In the Bullock Electrical Manufacturing Company's Works it is stated that for 127 h.p. of motors and lighting installed, the average load for working hours is only 27 h.p., a ratio of 1 : 4·8. This is rather a different case, however, since the lighting is included. Probably a ratio of 1 : 2 will in most cases be

ample allowance for a shop using separate motors to each machine, the amount of power for lighting *not* being included.

Until electric motors came into use for driving machine tools, very hazy notions seemed to prevail as to how much power a machine of a certain class or size demanded, and those who were least well informed were frequently the makers of the machines. A somewhat striking instance of this may be mentioned. A special form of grinding machine, for trueing up the edges of armour-plates, was put down at some steel works. The manager asked how much power would be required, and the makers told him 6 h.p. He thought he would be on the safe side, so ordered a motor to develop 10 h.p. When this was put to work complaints were made to the electrical firm who made the motor that it would not do its work; and as this was their first experience of electrical driving, and they were contemplating putting in a big power plant, they were much perturbed, and did not think electric driving was up to much. The electrical firm was very anxious to reassure them on this point, and the author was sent down to investigate matters. It was found that the motor was supplied with current from a small engine and dynamo of about 25 or 30 h.p. used for lighting, and the grinding machine was demanding more energy than the engine was capable of developing, and practically pulling it up short every few minutes. This was explained and demonstrated to the directors and managers, and permission was given to couple the motor up to a much larger dynamo used for welding. It was then found that the grinding was done in a highly satisfactory manner, but the motor was absorbing nearer 35 or 40 h.p. than the 10 h.p. for which it was built. It continued to do this for some months, occasionally demanding even 60 h.p.—a striking testimony surely to the good qualities of the motor. This result was highly satisfactory to all parties concerned, as there is now a power station with four sets of 200 h.p. each, and a corresponding load of motors for driving machine tools of all classes.

Let us pass on to the various applications of electric power. Travelling cranes are now almost invariably driven by electric motors, and every one agrees that this is an ideal method of applying power to this class of machinery. The

question of three-motor *versus* one-motor cranes has been much discussed. Possibly we shall have further discussion to-night. The balance of opinion seems to be in favour of three-motor cranes, though the one-motor type can be made to work quite as satisfactorily, in spite of what interested parties say. One firm of crane-makers who advocate the three-motor type to the exclusion of the other, built one of their earliest—if not the very first—cranes for a single-motor drive, and their experience with this has apparently been sufficient to change their views utterly. But the fault did not lie in the single-motor drive; it was the bad design and workmanship of the mechanical parts of the work—gearing, clutches, etc.—which caused the whole of the trouble. The author speaks feelingly, as this particular crane was a source of continual worry and trouble for over a year while under his control, until another firm practically rebuilt the crab, remodelled the gearing, etc.

If it be a case of putting in an entirely new crane, probably the three-motor type is advisable; but where an existing crane has to be altered from, say, a square-shaft drive, it is decidedly simpler and more economical to apply a single motor to drive the transverse shaft, and leave all the gearing and clutches as before. The author has had experience with several highly satisfactory examples of this arrangement. Liquid switches are a very convenient form of controlling gear for crane motors.

One or two somewhat interesting applications of motors to cranes have been made at Messrs. J. H. Holmes and Co.'s works. In the machine shop there are three Tangye hand travelling cranes in one bay. Since the time these were put up, the size of dynamos constructed has increased so enormously that it was a very slow business handling the heavy castings now dealt with. It was a somewhat difficult problem how to apply motors to the lifting motion, owing to the limited space between the crane girders, and the absence of head-room. However, a motor was suspended under the girders in a wrought-iron framing bolted to the crab. As this was of necessity somewhat lacking in rigidity, a spur or worm-gear reduction was out of the question. So an ordinary 1-inch pitch bicycle chain gear was used to transmit the power from the motor shaft to the hoisting gear. A stock size of sprocket wheel was screwed on the

motor shaft, and a steel disc about 18 inches diameter was cut in the milling machine to fit the chain, and this was fixed to the hoisting spindle.

A 5-ton traveller was first altered in this way, current being supplied to the motor through a flexible cable from a plug and socket on the wall near the works entrance, where most of the loading and unloading is done. It proved so successful, however, that wires were soon stretched along the shop in the usual way, so that the motor could pick up current, and the power lift be used from any position in the shop. A 3-ton crane has also been fitted with the same arrangement. The third crane in the bay has not been so fitted, and it is interesting to see how the shop labourers will always go and fetch one of these power-cranes from the other end of the shop if any heavy stuff has to be lifted, rather than use the hand-crane which happens to be close by. It should be made clear that electric power is only applied to the *lifting* of these cranes, and not to the travel and the traverse of the crab. The saving of time in lifting heavy weights is enormous. The motors are series wound, so the speed of lift automatically regulates itself according to the load to be lifted.

Another rather novel application of power has been made to a similar 3-ton hand crane on the floor above. It used to be a very slow, laborious job to lift heavy machinery from the ground floor to the first floor through a hatchway, the height of the lift being about 18 feet. So a motor was fixed down permanently on the floor at one end of the hatchway, and a cast-iron pocket wheel to fit the hand hauling chain was keyed to the motor shaft. The motor is fixed in such a position that when the hauling chain has been slipped over the pocket wheel, and the crab moved slightly across the shop to tighten the chain sufficiently, the crane hook is in the centre of the hatchway. By this means a load can be lifted from the ground floor in about two minutes, which formerly used to take four men about half an hour to do. Of course, in this instance the power lift is only applicable at this particular spot ; but, to enable loads to be moved about the shop, it is usually only necessary to raise them a few inches from the floor, which is not a long operation by hand. A similar arrangement has been fitted to a crane on the second floor also.

One very neat method of applying motors to machines is to suspend the motor on a hinged frame attached to the joists under the floor, and drive by a belt coming up through the floor. The weight of the motor keeps a tension on the belt, and, of course, with a large motor it must be partially counterbalanced to prevent too great a tension. Several machines in the pattern shop at Messrs. J. H. H. & Co.'s are driven in this manner, there being a basement below the shop. Circular saws and band saws are so driven, and a great deal of floor-space is thus saved.

There is a somewhat novel application of a motor in the pattern shop. It was necessary to provide a much larger lathe for turning up big magnet-ring patterns and similar things, and, as there was a five-horse power slow-speed motor available—the normal speed being 150 revolutions per minute—it was mounted on a cast-iron stool, and a disc flywheel attached to the armature shaft direct, to form a chuck or face-plate, to which work could be fixed in the usual way. Proper provision was made, of course, for taking up all end-play of the armature. Some dynamo slide rails were bolted to the floor in front of the motor, and a cast-iron pillar to support the T-rest can be moved in any direction on these rails to suit the work. This novel lathe will swing work up to about seven feet diameter, and has proved very successful. The speed can be varied from 150 to 600 revolutions per minute by shunt-resistance. An ordinary lathe to swing this diameter of work would have been an expensive matter. Also, it was possible to fix this close against the wall, thus taking up much less space than a lathe would occupy.

A radial drilling machine for drilling and tapping up to 2 in. diam. holes is driven by a two horse-power motor, the gearing being a Hans Renold silent driving chain. The motor is mounted on the cast-iron box containing the gear wheels of the machine at the back of the pillar, the distance between centres of motor and machine shafts being only about two feet. The starting and speed regulating switches are mounted on the pillar, close to the man's hand.

While speaking of drilling machines, mention should be made of the application of electric motors and flexible shafts. The motors are usually mounted with their reduction gear complete on wheels, so that they can be readily run about

from one place to another. The "Stow" flexible shafts are usually about eight feet long, and are coupled to the motor shaft by a universal joint coupling. The shaft may be curved and bent in any direction, and with a suitable drill press, holes up to 2 in. diam. can be drilled with a $1\frac{1}{2}$ h.p. motor. The convenience of these outfits in shipbuilding, bridge, and building construction can only be realised after they have been employed. The current is conveyed to the motors by an armoured flexible cable, which may be of any length required. Smaller motors and flexible shafts for use with a breast drill press, for holes up to $\frac{3}{8}$ in. diam. are also largely used. In many cases a self-fixing magnetic drill post can be used with advantage in place of the ordinary "swan-neck." These magnetic pillars or posts hold on with an astonishing force. The author tested one in drilling a hole $1\frac{1}{2}$ in. diam. in cast iron, the magnet only taking rather less than 1 ampere at 120 volts. The weight of the post was about 50 lbs., and it required a direct pull of 16 cwt. to detach it from a rough machined steel surface.

Another very neat portable drilling tool was brought out a year or two ago by one of the leading electrical firms in the country, for drilling small holes rapidly in the thin deck plating of torpedo boats. This motor and reduction gear is enclosed in a metal case, with the drill projecting at the bottom. There are two handles, one at each side, on which the workman presses when drilling, and by which the machine is carried from point to point. It only weighs about 60 lbs., if the author remembers rightly. A test, made in one of the shipyards on the Clyde, proved that about 600 holes 3/16 in. diam. could be drilled through a plate $\frac{1}{8}$ in. thick in one hour.

Perhaps driving a planing machine with a separate motor is about the most severe work to which a motor can be put, as the load at the moment of reversal with a great weight on the table runs up to three or more times the normal current. If a motor drives the planer by open and crossed belts, and runs continuously in the same direction, a heavy flywheel on the motor shaft is of great assistance in helping it over this sudden strain. In one case with which the author had to do, a very large vertical and horizontal planer—or wall planer, as it is sometimes called—was driven by a compound-wound motor, with the series helping the shunt, and thus

the considerably higher speed at which the motor runs at light load was of advantage in the return or non-cutting stroke.

Another case of power being under-estimated by the machine tool makers was in the case of a slab milling machine for milling surfaces up to 18 in. or 20 in. wide. For a specified depth of cut and rate of feed they estimated it would require 6 h.p. to drive it, whereas it was found that the power absorbed was nearer 15 h.p. Two motors were applied to this milling machine eventually, one to drive the cutter and the other—a smaller one—to drive the feed motion and table. In both cases the speed could be varied within very wide limits by means of resistance in the shunts. The feed and speed being entirely independent, was found of great advantage in this case. A comparison was made between a slab milling machine, using a fluted spiral cutter of the ordinary pattern for heavy work, and a machine which was really a cold sawing machine, but which was fitted with a milling or facing head, having inserted tools or cutters. It is interesting to note that the latter class of milling only absorbs about one-half the power for a given weight of material removed in a given time. This is due to the fact that the cuttings are much larger and thicker, similar to the cut of a lathe or planer, while the ordinary milling cutter removes the metal in very much finer particles.

Horizontal boring and drilling machines can very suitably have the motor mounted on the rising and falling head or saddle of the machine, and geared direct by spur gearing. A machine of this class has been so fitted recently. It was formerly driven from the main shafting and a countershaft. A jockey pulley and weight arrangement was necessary to keep tension on the driving belt, for, when the saddle of the machine was raised or lowered to suit the work, the length of the belt varied greatly, the drive being at an angle of about 60 degs. The application of the motor has dispensed with this unsightly arrangement, and has enabled the machine to be moved to a more convenient position at the opposite side of the bay.

It is sometimes more convenient for lifting work on and off certain classes of machines—say, horizontal lathes and radial drills—if they are fixed at right angles to the walls or columns. This is not usually very practicable with belt

driving from the shafting, but can be readily arranged when driven by separate motor. A boring mill was arranged in this manner recently, the countershaft being supported at one end by a hanger bearing under the travelling crane gantry and at the other end by a pedestal bearing fixed on the top of the boring mill. The motor was fixed on an angle bracket bolted to the side of the machine, and is belted to the countershaft by a short belt. The switches are arranged at the opposite side of the machine, near the feed handles, &c.

In the case of very large and comparatively slow running lathes and boring mills, a motor is sometimes coupled direct to one of the cone pulleys of the machine, and mounted on a bracket on the wall, to drive down to the cone pulley of the machine. Or, if a motor with very large range of speed be used, it is coupled direct to the lathe gearing, and so dispenses with the cone pulleys and belt altogether. Some very large lathes for ordnance work had hinged frames attached at the back of the headstock. A cone pulley corresponding to the lathe cone was fitted on the motor shaft, and the motor mounted on the hinged frame. The weight of the motor then kept the requisite tension on the belt, as it tended to fall away outwards from the headstock. A very short belt was sufficient, and the arrangement took up very little space. In connection with one of these large lathes, when first fitted with a motor the workman in charge was very sceptical about how much work he could turn out of his lathe. He asked how big a cut he might put on without pulling it up, and was told to put on all he could. He was turning a heavy gun forging of about 30 tons, and there were two saddles on the lathe with four tools in each. When he got them all taking their full cut he was very much astonished that it apparently made not the slightest difference to the motor, which, of course, ran as quietly and practically at the same speed as before. He was genuinely converted to electric driving.

A very convenient little tool can be made by mounting a small motor, say ¼ h.p., on a square steel bar, and attaching an emery wheel direct to the armature spindle. If any lathe centres have to be trued up, this apparatus can be bolted on the tool post of the saddle, and readily used to grind up the live centre.

Nothing has been said about the relative merits of various forms of gearing, as this seems rather outside the scope of an electrical paper. The question as to which is best suited for a particular purpose depends largely on the circumstances of each case; but direct-coupling, belting, pitch chains, Hans Renold chains, spur worm and friction gearing, have all been used with very satisfactory results in electrically-driven machine tools. The author may mention that a most interesting friction gear for reducing speed has recently been brought out by a gentleman named Brown, and is called the "Twentieth Century Gear." It seems to have some excellent points for use in connection with small high-speed motors, though no figures are available yet as to its wearing qualities. It is an internal rim friction device with three rollers, two of which revolve on fixed spindles, while the other is free to change its position somewhat according to the torque. The low-speed friction driven rim or pulley is concentric with the motor spindle, and takes up no more space than an ordinary pulley would do. The efficiency seems to be remarkably high. Worm gearing is often employed where a very large reduction of speed is necessary, and in cases where it is important that motion cannot be transmitted in the opposite direction, for instance, in hoisting motions of cranes, where the load will be self-sustaining, with a single or double-threaded worm. Worm gear is somewhat expensive to make. Spur gearing is largely employed, and cut gears are used in nearly all cases for high-speed work. The use of raw-hide pinions has proved of great advantage in motor reduction gearing, and runs very quietly. Chain gearing is very suitable in many cases where the drive is short, though too great or not rigidly enough fixed to enable spur gearing to be used. It is generally less noisy than spur gearing, and has the advantage of positive drive, which belting has not. Direct-coupled motors are useful for machinery which runs at a high speed, such as fans, blowers, grinding machinery, &c. For slow-speed machinery they become very heavy, and, of course, more costly, and rather less efficient; though the absence of noise and wear and tear of gearing, &c., compensates for these points in many cases.

In conclusion, it is not necessary to dwell upon the advantages of electric power transmission in general, over shafting

and gearing in factories—these are becoming fully recognised in all branches of manufacture, and the reasons are not difficult to find. In nearly all cases works grow in size, and are extended and added to bit by bit. A new pattern shop, new foundry, or a shop for any special purpose may be built quite apart and any distance from the main building. It is hardly necessary to state how much easier it is to provide these detached shops with power by means of a couple of wires and a motor, than in the old method of erecting a long line of steam piping or line of shafting, involving perhaps the use of bevel gearing or half-twist belts, to say nothing of the difference in efficiency. If works were put down at the outset for the maximum output they were ever to attain, some of these advantages of electric driving would disappear; but is this ever the case in business? A works must grow, like everything else, in the natural course of things.

Everyone engaged in the trade—or shall we say, "profession?"—of electrical engineering is anxious to see the use of motors extended, and if this short paper prove of some slight assistance towards that desirable end, by directing attention to their application to this special class of work, the author will not have occupied your time in vain.

We are indebted to the courtesy of Messrs. J. H. Holmes and Co. for the series of lantern slides with which the paper has been illustrated. Many of these have been specially prepared during the last week for the purpose by their works photographer.

Mr. Moir.

Mr. ALEX. MOIR: I think Mr. Ralph's paper has been an eminently practical one, all the greater in value because it has dealt to a great extent with motors in actual use at Messrs. Holmes' works. Recently I had an opportunity of going over a new and fairly large printing works in Yorkshire, where electric driving had been adopted. Each printing-press was supplied with an independent motor, and the proprietors, who had carefully balanced the relative advantages and costs of steam and electricity, were more than satisfied with the result of their decision in favour of the latter. They had saved considerable capital outlay, and owing to its being possible to run just such motors as were really required to do actual work, at any hour of the day or night, without having to pay for attendance upon a steam engine plant, turning round shafting that would sometimes have been only very lightly loaded, real economy had been effected. On the other hand, an instance recently came under my notice which proved, as Mr. Ralph has indicated, that electro-motors cannot compete at present with other

descriptions of motive power, unless the economies that the use of motors renders possible can be practised. In this case a gas engine was used for driving a central shaft from which several light machines in a machine-tool shop were driven. The weekly gas bill was £1 15s. To have replaced this engine by a single motor—it was not possible to use more than one—would have cost, at existing Tyneside energy rates, just £4 per week. Mr. Moir.

Mr. C. TURNBULL: I think the tendency in the future will be more and more to use portable electrically-driven tools, especially for big work. By this means the weight of heavy castings will cease to be a cause of great expense in working, as they will not need much moving. Mr. Ralph mentioned a case in which a temporary lathe was rigged up for boring out a magnet, and it answered very well. The question arises, Why not always use such methods and save the cost of large tools? It would seem also that, in works where dynamos are made, generator-sets on test might be used to provide power for use in the factory. If this could be done, instead of all the power being sent to waste, there would be a great saving. The voltage could be adjusted by negative or positive boosters, while the load could be kept fairly steady by means of supplementary resistances. Integrating wattmeters could be used to measure the energy given off by the generator, so that there would not be trouble from unavoidable variations in the current due to machines driven from the generator stopping and starting. Mr. Turnbull

Mr. F. BROADBENT: I agree with the previous speakers as to the practical nature of this paper by my colleague, Mr. Ralph. It is all the more valuable in that it tells us what has actually been done and proved by experience to be good rather than theorises as to what might be done. It is a little disappointing, however, that no general principles are laid down as to the best methods of motor driving, the facts being in most cases merely stated and no conclusions drawn. Mr. Broadbent

In most of the examples given the question of convenience appears to have been the chief consideration rather than that of cost: that is to say, that it has generally been found more convenient, having cables handy and a scrap motor in stock, to make use of these instead of fitting up new shafting and pulleys to drive the particular machine under consideration. In many of the examples given the combined machine and motor have no doubt paid for themselves in a very short time, and this, I believe, applies more particularly to the boring mill mentioned, which paid for itself on its first job. We cannot, however, generalise from these data, and say that it will always pay to drive a boring mill by a motor. No; the special conditions obtaining in this case are responsible for the success. This bears out Mr. Ralph's remark that each case must be considered on its merits. Apart from special conditions, however, one would think that some general rule might be made for machine tool driving in ordinary engineering shops as to the smallest size of motor it is practicable and profitable to use. It is on this point I should like to have heard more.

As to the losses in shafting, we have come to believe that 50 per cent. is a fair average efficiency to obtain for shafting, and I was some-

and gearing in factories—these are becoming fully recognised in all branches of manufacture, and the reasons are not difficult to find. In nearly all cases works grow in size, and are extended and added to bit by bit. A new pattern shop, new foundry, or a shop for any special purpose may be built quite apart and any distance from the main building. It is hardly necessary to state how much easier it is to provide these detached shops with power by means of a couple of wires and a motor, than in the old method of erecting a long line of steam piping or line of shafting, involving perhaps the use of bevel gearing or half-twist belts, to say nothing of the difference in efficiency. If works were put down at the outset for the maximum output they were ever to attain, some of these advantages of electric driving would disappear; but is this ever the case in business? A works must grow, like everything else, in the natural course of things.

Everyone engaged in the trade—or shall we say, "profession?"—of electrical engineering is anxious to see the use of motors extended, and if this short paper prove of some slight assistance towards that desirable end, by directing attention to their application to this special class of work, the author will not have occupied your time in vain.

We are indebted to the courtesy of Messrs. J. H. Holmes and Co. for the series of lantern slides with which the paper has been illustrated. Many of these have been specially prepared during the last week for the purpose by their works photographer.

Mr. Moir.

Mr. ALEX. MOIR: I think Mr. Ralph's paper has been an eminently practical one, all the greater in value because it has dealt to a great extent with motors in actual use at Messrs. Holmes' works. Recently I had an opportunity of going over a new and fairly large printing works in Yorkshire, where electric driving had been adopted. Each printing-press was supplied with an independent motor, and the proprietors, who had carefully balanced the relative advantages and costs of steam and electricity, were more than satisfied with the result of their decision in favour of the latter. They had saved considerable capital outlay, and owing to its being possible to run just such motors as were really required to do actual work, at any hour of the day or night, without having to pay for attendance upon a steam engine plant, turning round shafting that would sometimes have been only very lightly loaded, real economy had been effected. On the other hand, an instance recently came under my notice which proved, as Mr. Ralph has indicated, that electro-motors cannot compete at present with other

descriptions of motive power, unless the economies that the use of motors renders possible can be practised. In this case a gas engine was used for driving a central shaft from which several light machines in a machine-tool shop were driven. The weekly gas bill was £1 15s. To have replaced this engine by a single motor—it was not possible to use more than one—would have cost, at existing Tyneside energy rates, just £4 per week. Mr. Moir.

Mr. C. TURNBULL: I think the tendency in the future will be more and more to use portable electrically-driven tools, especially for big work. By this means the weight of heavy castings will cease to be a cause of great expense in working, as they will not need much moving. Mr. Ralph mentioned a case in which a temporary lathe was rigged up for boring out a magnet, and it answered very well. The question arises, Why not always use such methods and save the cost of large tools? It would seem also that, in works where dynamos are made, generator-sets on test might be used to provide power for use in the factory. If this could be done, instead of all the power being sent to waste, there would be a great saving. The voltage could be adjusted by negative or positive boosters, while the load could be kept fairly steady by means of supplementary resistances. Integrating wattmeters could be used to measure the energy given off by the generator, so that there would not be trouble from unavoidable variations in the current due to machines driven from the generator stopping and starting. Mr. Turnbull

Mr. F. BROADBENT: I agree with the previous speakers as to the practical nature of this paper by my colleague, Mr. Ralph. It is all the more valuable in that it tells us what has actually been done and proved by experience to be good rather than theorises as to what might be done. It is a little disappointing, however, that no general principles are laid down as to the best methods of motor driving, the facts being in most cases merely stated and no conclusions drawn. Mr. Broadbent

In most of the examples given the question of convenience appears to have been the chief consideration rather than that of cost: that is to say, that it has generally been found more convenient, having cables handy and a scrap motor in stock, to make use of these instead of fitting up new shafting and pulleys to drive the particular machine under consideration. In many of the examples given the combined machine and motor have no doubt paid for themselves in a very short time, and this, I believe, applies more particularly to the boring mill mentioned, which paid for itself on its first job. We cannot, however, generalise from these data, and say that it will always pay to drive a boring mill by a motor. No; the special conditions obtaining in this case are responsible for the success. This bears out Mr. Ralph's remark that each case must be considered on its merits. Apart from special conditions, however, one would think that some general rule might be made for machine tool driving in ordinary engineering shops as to the smallest size of motor it is practicable and profitable to use. It is on this point I should like to have heard more.

As to the losses in shafting, we have come to believe that 50 per cent. is a fair average efficiency to obtain for shafting, and I was some-

Mr. Broadbent. what surprised on recently visiting a large engineering works in Bradford, where certainly the advantages of motors were understood, to find that motor driving was only adopted in a few cases, whilst the main shafts, newly put up, were driven by a steam engine. The owner assured me that from careful tests of the H.P. used in driving the shafting light, that is doing no work, but with all belts on, he found the efficiency to be 85 per cent. It would not have been possible by separately driving the machines by motors to have improved on that.

Notwithstanding this, however, the owner intended taking one or two of the largest machines off the shafting, and putting in separate motors, because of the time wasted in shifting the belts on the coned pulleys to get the various speeds required. Now, it is on this point that I must disagree with Mr. Ralph. On page 547 he says, "The average machine hand will not take the trouble to shift his belt to suit the size of the work unless he is constantly watched by the foreman." He puts this down to laziness. It is not altogether laziness. In the case just referred to, the machines were very large, and it would take two men a considerable time to shift the heavy belt from one pulley to the next, and as this speed might not be required for very long, the same amount of time would be wasted in shifting the belt back again in a short time. Now, if the man had kept the belt on the slow speed all the time, and never stopped, he would probably have turned out just as much work. It is here, then, that the advantage of motor driving comes in. Instead of wasting time shifting a heavy belt, or alternatively keeping the machine on the slowest speed, you have only to move the handle of the regulating switch up a few notches to get just the speed required. In this way the output from any variable-speed machine can be very considerably increased, as, instead of being tied to three speeds, as in cone-pulley driving, any intermediate speed can be got to suit the work. In the case of printing machine driving, the use of motors has in many cases increased the turnover by 25 per cent., and as wages and standing charges are not increased, this, of course, means greater profits, and the cost of the motor is soon paid for. It is sometimes difficult to show on paper any advantage in installing a motor. This applies more particularly to comparisons with gas-engine driving. Gas seems to be far cheaper on a steady load. In spite of this, cases are known in which a saving has been shown by replacing a gas engine by a motor. The reason is that, except in rare cases, the load on a shaft is not constant, and whereas a gas engine takes very little note of the variations in load, but just consumes as much gas as though doing its maximum output all the time, a motor does, on the contrary, note every little irregularity, and its consumption of energy varies in proportion.

These two points—the variation of load, and the variation of speed—are to my mind very important factors to consider in estimating the costs of alternative methods of driving.

Mr. Dobbie. Mr. R. S. DOBBIE: I wish to join in congratulating the author on his paper. In speaking of the loss in shafting, I have seen several cases where good shops, properly laid out with hangers of the best description, have been changed over from a steam or gas-engine drive to an electrical drive. In one case a line of shafting 320 feet long,

driving eight or ten very heavy machines, absorbed something like 14 H.P. running light, with all the machine belts on loose pulleys. When all these heavy machines were running, the average power taken was at first about 28 H.P., and I thought we were overrating the power required for the machines, but found that it was one of the snares which the author has mentioned, and that, on occasion, much more than the 40 H.P. provided was called for. Certain machines appear to take but little power, but the conditions, if changed, show otherwise. In the case of the power necessary for a generator, I have lately installed a 32-k.w. generator for driving shafting in an emergency, due to a fire. Having had a little trouble, I found that we had a load as high as 70 k.w., and an average of 40 k.w. was called for, which shows how carefully we must install these things in order to get good results. It is not only the initial estimation that must be considered, but the increments that come from continued extension. The author mentioned a 10-H.P. motor demanding 60 H.P. I would like to ask how much came out of the motor under these circumstances. I can sympathise with the trouble of the lecturer with the electrically-driven single-motor cranes. I know of rope-driven ones that have been converted into single-motor cranes, but they have never worked satisfactorily. I have seen large castings held on a planing machine by magnetism. Machines of this type are used to a large extent in planing and grinding delicate work. In the case of large castings strips of iron and the like are used to prevent end movement. In America I once converted a shop, belt-driven from steam engine, into an electrically-driven shop; the factory consisted of five stories, including a basement, and was engaged in making small machinery weighing two or three hundredweight complete. The transmission was originally effected by means of belts and occasional bevel-wheels. These were all taken out, and a dynamo was run by the same engine that previously drove the belts, and the saving in power was something enormous. The factory originally took 260 H.P. to run everything, but when all the machinery was not in use it absorbed 160 H.P. In the case of electrical driving it took 160 H.P. to drive the whole shop, and when everything was turned off the H.P. indicated was only the friction load of engine and dynamos running light. Mr. Dobbie.

Mr. H. H. BIGLAND: Many of us have felt pleasure at hearing Mr. Ralph's paper, but there is one point that has been left rather vague. Several have spoken somewhat vaguely of small motors. I was hoping that the author would state the actual facts or would give his experience of the smallest-sized motors which he has put down. It is a matter that I have lately had under consideration. On referring one point to Messrs. W. H. Allen, Son & Co., Limited, the firm with whom I am, they have informed me that at their Bedford works, in twelve months, small portable drills have paid for themselves, and they are strong advocates of "small motors" (the term is vague, but we may at any rate say as low as $\frac{1}{4}$ H.P.) In most cases I have carefully looked into, I think they will be found economical. I have not, however, been able to see how, in the case of quite small lathes, the difficulty of the tool becoming jammed is to be sur- Mr. Bigland.

Mr. Bigland. mounted. I am anxious to know whether the fuses would blow, or what damage would accrue in direct driving. These are serious difficulties if occurring frequently. The question of gas-engine driving appears to be coming to the front if we credit the papers on Mona gas. Indeed, I have heard of a firm not very far from this town who have had experts engaged in sifting the matter thoroughly, and it appears possible that direct gas-engine driving coupling short lengths of shafts may be used by them in preference to electric motors. People seem rather to have ignored the fact that gas-engines now are worthy of consideration, and I think if any practical gas engineers are here they will question what Mr. Broadbent says about the consumption of gas being almost the same at full load as at half-load; but these are all points that I would like information on.

Mr. Le Rossignol. Mr. Le Rossignol: I agree with the remark that one cannot so much discuss the paper as endorse all it enunciates. Mr. Ralph's remarks on the advantages of electrical driving are very much strengthened by the fact that this method of workshop driving is greatly used on the Continent and in the United States. I recently visited some of the largest locomotive and stationary engine works and large electrical works in the latter country, and endeavoured to find out why the Americans were able to turn out similar articles in quicker time than can be done in this country, and I can only attribute this to the far greater use they make of electrical driving. In these large works the principle had been largely adopted of tooling and finishing large castings by means of machines brought to the work. These machines were frequently of large size, were electrically driven, and could be lifted about and attached to the work without any difficulty, and thus large pieces could be completely finished without once being moved from their place or even turned over. Large generator-rings up to any diameter, fly-wheels up to forty feet in diameter, and other heavy pieces of machinery, were thus dealt with at a very small cost. In some of the large steel works the whole of the handling of the material was done by mechanical means: large electrical cranes lifted the ingots out of the reheating furnaces and deposited them on electrical travelling carriages. These carriages tipped them on live roller gangs, which carried them to the rolls, so that an ingot from its start from the furnace was not touched once by hand till it came to the cooling-table as a finished rail or girder.

There is no doubt that great economy in labour can be effected by an extensive adoption of electrical driving in all sorts of manufacturing processes, and in time I trust that manufacturers in this country will come to see the benefits which can be obtained by this means.

Mr. Heaviside. Mr. A. W. Heaviside (*Chairman*): I do not know that I can add anything important to this very interesting subject; but upon the question of the sub-division of power, I may say that on a visit to Switzerland I observed in a silk factory at Wädenschwyl, on the banks of the Lake of Zürich, that every girl operator had her own electric motor. These would be probably from $\frac{1}{8}$ to $\frac{1}{4}$ H.P., and we may be sure that, with a thrifty practical race like the Swiss, the motors would not be there if they were not commercially successful. In my opinion

there is no question that the electric motor must predominate if the current can be had at a reasonable rate, such as 1d. to 1½d. per unit, as is likely to be the case in this neighbourhood. In that case the gas-engine, with its cost of up-keep and the necessary special place it must occupy, is out of the running. You cannot put a gas-engine in a drawing-room, whereas you can put an electric motor there. Mr. Heaviside.

Mr. G. RALPH (in reply): I must express my thanks to all the members who have taken part in the discussion for their kind remarks, and to the meeting in general for their kind reception of the paper. Mr. Ralph.

Mr. Turnbull makes the suggestion that during the testing of dynamos, the power might be utilised for driving the machinery in the works, instead of running the current to waste in resistances. As a matter of fact, this *is* often done, when the voltage of the machines under test is at all suitable. It so happens that to-day the whole of the current required for power and lighting has been supplied to the works from a steam dynamo running under a ten hours' test. A considerable saving of fuel can be effected by this means. I am glad to hear Mr. Le Rossignol's confirmation of the views expressed as to the advantages of portable tools, &c. Mr. Moir's kind remarks do not call for any reply.

Mr. Broadbent thinks that too much stress is laid on convenience, rather than on relative cost. I admit that I have not attempted to go into the question of cost, with which he is far more competent to deal than I am. But, leaving capital outlay out of the question, it may fairly be said that when convenience is aimed at, and attained, cost (or wages) is reduced, and thus one factor is dependent on the other. He does not agree with me on the point of shifting of belts to get the correct speed on machines. Probably in the case of large heavy belts he is right, but with an ordinary 3″ or 4″ belt it is only a matter of a minute or two to shift from one cone step to another; and I think that most shop foremen and managers will agree with me that the neglect of utilising the means provided for getting the most work out of tools is largely due to laziness or indifference on the part of the operator. With regard to the losses in shafting, I think the owner of the particular factory referred to is to be highly congratulated if the loss is only 15 per cent.

Mr. Broadbent, and Mr. Bigland also, express disappointment because it is not stated definitely what is the smallest size of motor it is profitable and practicable to use for individual machine tool driving. I stated that I considered about 2 H.P. was a reasonable size to employ, but at the same time the conditions vary so much that one cannot make any very definite statement on this point.

Mr. Dobbie's remarks on shafting confirm what is stated in the paper. With regard to single motor cranes, it was only in one particular instance that I had an unhappy experience, and I am rather surprised to hear that he has found converted cranes unsatisfactory with a single motor drive. The one to which I referred was a new crane, and would have proved unsatisfactory with any method of driving, for, as explained, the bad workmanship was largely at fault. The case mentioned of a 10 H.P. motor demanding 60 E.H.P. is a very

Mr. Ralph. extreme case, and, of course, the C^2R losses would be very great, and the efficiency correspondingly low. I am much interested to hear of the magnetic hold-on devices for chucks and planer tables, and should much like to hear further details. I know that for grinding thin articles they are very satisfactory.

In further reply to Mr. Bigland, we have used motors of all sizes, from ¼ H.P. upwards. His remarks on portable electric drills fully bear out my own.

With regard to what happens to a small motor if the machine it is driving jams, or pulls up, probably the fuses would blow, or the belt would come off (and in practice, small machines usually are belt driven). In the case of a large machine driven by spur or chain gearing, if there is no overload release on the starting switch, probably the fuses will blow, which is not a very serious matter, although Mr. Bigland seems to think so. If it happens *frequently*, as he suggests, then there would probably be something the matter either with the method of doing the work, or with the workman, which would require prompt attention, not necessarily of an electrical nature! I must confess my surprise at a number of gas engines being used in any works to drive short sections of shafting in preference to electric motors. I do not imagine it is a method which will be largely adopted. I quite agree with Mr. Patterson's remarks on the grouping of small machines on to one line shaft.

Mr. Heaviside mentions an interesting example of individual driving, where the sub-division of power is much greater than is usual in this country; but there may be special circumstances in the particular case which justify it. The point he mentions about the space occupied by gas engines, compared with electric motors, is an important one.

GLASGOW LOCAL SECTION.

The Glasgow Local Section of the Institution of Electrical Engineers met in the large hall of the Institution of Engineers and Shipbuilders in Scotland, 207, Bath Street, Glasgow, on Wednesday, the 13th of February, Professor Magnus Maclean (Vice-Chairman) in the chair.

The CHAIRMAN explained that this was the first meeting since the Nation was thrown into mourning by the lamented death of the late Queen, and he stated that the Committee had held a special meeting and had, on behalf of the Section, passed resolutions of condolence and loyalty, which had been forwarded to the Home Secretary, and he asked the present meeting to confirm the resolutions so passed, which were: "That this Special Meeting of the Committee, on behalf of the Glasgow Local Section of the Institution of Electrical Engineers, desires to express its deep sense of the loss sustained by the death of their late beloved Sovereign, Queen Victoria, whose long beneficent reign has been marked by such social and scientific progress"; and "That an expression of confidence and loyalty be sent to His Most Gracious Majesty King Edward, with the hope that he might long be spared to reign over an attached people."

A METHOD OF COMPENSATING VOLTMETERS FOR THE VOLTAGE DROP IN LONG FEEDERS.

By MICHAEL B. FIELD, Member.

A problem which often confronts the central station engineer is the measurement at the power-house itself of the voltage obtaining at distant parts of his network which supplies current for, say, lighting and power purposes. In fact, it is very often of far greater importance that the engineer in charge should know accurately the value of the voltage existing at the distributing network, or, better, the lamp terminals or motor terminals, as the case may be, than that obtaining at the central station bus-bars themselves. In cases where the distributing network lies at some con-

siderable distance from the power-house, and is fed with current by means of "feeders," the drop of voltage in the latter may vary from zero, when the network is very lightly loaded, to 10 or 12 per cent. when the network is heavily loaded. Under such circumstances the engineer requires, of course, so to regulate his generators that the voltage at the network or lamp or motor terminals remains constant; in other words, he must raise the bus-bar voltage in the power-house above the normal by an amount equal to the drop in the feeders.

In such cases a very usual course to adopt is to mount on the switchboard in the central station voltmeters which are connected to points of the network by means of "pilot" wires, and thus indicate the true voltage existing at those points. The engineer in charge can then readily regulate his generators so that, under varying conditions of load, the voltage indicated by these voltmeters is maintained constant.

In the year 1882 Dr. Hopkinson patented an arrangement for effecting the same purpose without resorting to the employment of pilot wires. His method consisted of compounding the shunt windings of electromagnetic voltmeters with a few turns of thick wire, through which the main feeder current, or a proportionate part thereof, flowed. In this way a voltmeter connected to the near end of a pair of feeders might be compensated for the drop along the feeders, and would thus indicate the voltage existing at the far ends, and obviate the necessity of employing pilot wires.

There is, of course, no great disadvantage in employing pilot wires for the purpose named beyond the cost of the same, which will amount to at least £90 per mile per twin wire. If it be possible to save this sum, which, especially in the case of long-distance transmissions or networks covering extensive areas, will amount to a very considerable sum, by merely adding a suitable arrangement of resistances at the switchboards, it will of course be advantageous to do so. Moreover, by obviating the pilot wire, we obviate the trouble often connected therewith; and while speaking on this point I would call attention to the fact that it is by no means uncommon for pilot wires to give trouble. What the reason usually is I do not know. Whether it is that while laying them they are considered as an adjunct of no vital

importance, and therefore the necessary care is not devoted to their instalment, or whether it be for other reasons, is not a matter for discussion here.

Compounding coils of the above description are of course quite inapplicable to voltmeters constructed on the D'Arsonval principle, *e.g.*, Weston voltmeters, and in consequence of the almost universal preference shown by central station engineers for instruments of this class for continuous-current work, the writer some little while ago devised a method whereby any voltmeter whatever may be compensated for the feeder drop of either a two, three, or multiple wire system without necessitating constructional modifications of any kind, and, beyond that, can be arranged to indicate the *average* voltage obtaining at *any group* of distant feeding-points.

The method is capable of very general application, but three instances of its use are of special interest to central station engineers, and it is the object of this short paper, firstly, to describe briefly these three applications, and, secondly, to investigate analytically the accuracy of the same. The three cases for consideration are:—

(*a*) The measurement on the same instrument not only of the actual voltage existing at various feeding-points of a two-wire network, but also the *average* of the voltage at all the feeding-points, or the average voltage at any desired group of feeding-points of the network.

(*b*) The measurement of the individual feeding-point voltages and the average voltage at any group of feeding-points of a network on the three, five, or other multiple-wire systems.

(*c*) The measurement by means of a low-tension electrostatic multicellular voltmeter of the voltage at the far end of a long single- or multiphase-power transmission line working at extra high tension, and possibly possessing a comparatively large self-induction.

Let us imagine a large distributing network supplying current for lighting and power purposes over a considerable area. It is evident that a voltmeter in the power-house so

arranged that it indicated directly the average of the voltage all over the network would provide the engineer in charge with much more valuable information than one arranged only to indicate the actual voltage at some particular point of the network, for it is clear that the engineer should strive to maintain the average voltage at the normal value. Now, although it is not easy to obtain the true average of all points of the network, this may be approximated to by measuring the average voltage existing at all the feeding-points; this information would as a rule be a sufficient guide to enable the central station engineer to maintain the average voltage over the network itself at its normal value.

It might further be advantageous for the engineer to be able to measure the average voltage existing at some one group or other of feeding-points, *e.g.*, during one portion of the day he might perhaps wish to pay most attention to keeping the average voltage throughout the commercial portion of the town constant, and at another time it would be of more importance to maintain the average voltage throughout the residential portion of the town constant. He might further wish to know at any instant what was the actual voltage at the end of some one long feeder supplying an outlying district, more especially if this feeder contained a booster so that the voltage was capable of independent regulation; all of these conditions become possible by the method about to be described.

Case A.—The additional switchboard apparatus necessary for this case—for, say, a continuous-current system—consists of a low-reading Weston voltmeter with a suitably graduated scale (*e.g.*, an ordinary 600-volt Weston with the series resistance removed would serve perfectly), a multiple contact voltmeter switch, a set of voltmeter resistances which would be mounted in an out-of-the-way place at the back of the switchboard, and, further, a series resistance for insertion in each feeder circuit. These latter resistances would be similar to those usually supplied with Weston ammeters, and would be such that the drop across them with the maximum current would be of the order of $\frac{2}{10}$th volt, or less where exceptionally heavy feeder currents are dealt with.

The multiple contact switch would be arranged for as many "positions" as groups of feeding points required.

Suppose, for example, three feeding circuits A, B, C left the station, a four-way voltmeter switch might be advantageously employed. With the switch successively in the first three

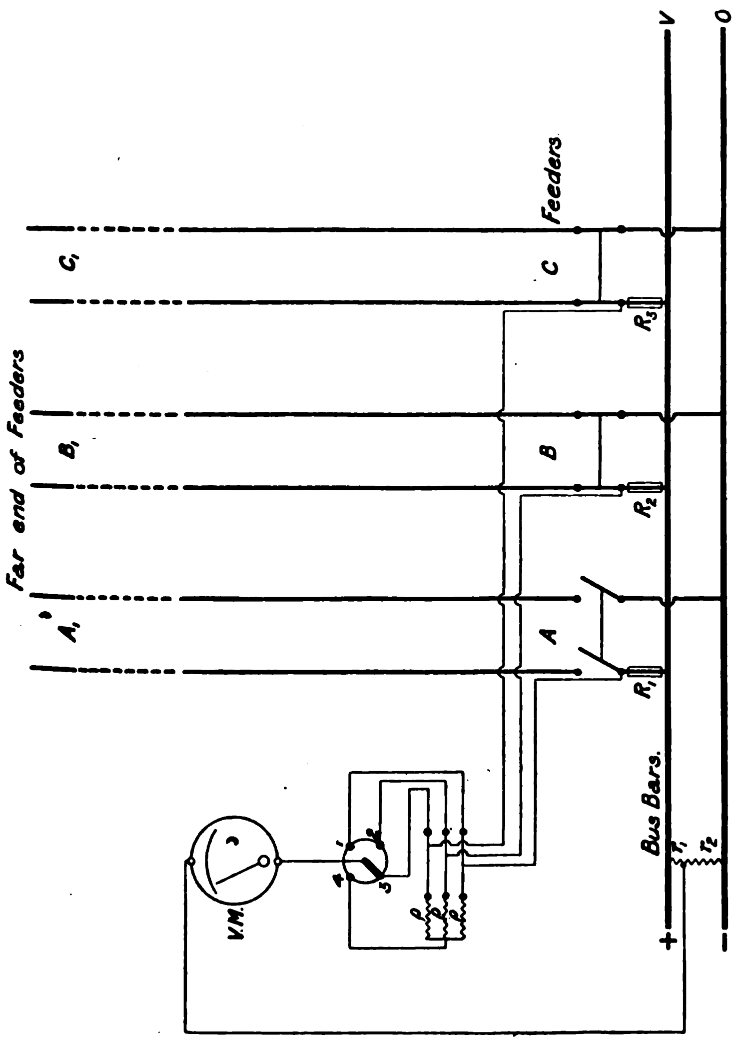

FIG. 1.

positions the voltmeter would indicate the feeding-point voltage of the network at A_1, B_1, C_1 respectively, while with the switch in the fourth position the voltmeter would indicate the average voltage at the feeding-points A_1, B_1, C_1.

Two distinct arrangements are shown in Figs 1 and 2.

Fig. 1 shows the simpler of the two, but involves the disadvantage that the average voltage of A_1, B_1, C_1 can only be obtained if all three feeding circuits are switched in. It is, moreover, only possible to determine the individual values A_1, B_1, and C_1 if the corresponding feeders be switched in.

In Fig. 2, on the other hand, a modification is shown whereby the individual voltages A_1, B_1, C_1, and the average of A_1, B_1, C_1, are given correctly by the voltmeter with the switch in the corresponding positions, whether some of the feeder circuits be switched in or not.

This involves extra complication in the multiple contact switch, in which case it may conveniently be constructed on the same lines as a miniature tramcar controller. In Fig. 2 the contact cylinder has, for the sake of clearness, been developed on a plane.

R_1, R_2, R_3 are the inserted series resistances in the feeder circuits; shunt resistances (divided into r_1 and r_2) are connected in Fig. 2 across each pair of feeders, in Fig. 1 across the bus-bars. The letter ρ represents that the particular connecting wires so distinguished must have sufficient resistance to prevent any appreciable interchange of current between the various feeder circuits when the switch is in the fourth position. V.M. is the voltmeter, and s a shunt which is connected across the terminals of the voltmeter when the switch is in the fourth position, in order to keep the calibration of the voltmeter correct.

Briefly explained the principle involved is as follows:—

If r_1 be $(\frac{1}{n})$th part of $r_1 + r_2$, the drop of pressure down r_1 will be $(\frac{1}{n})$th part of the bus-bar volts. Again, if R_1 be $(\frac{1}{n-1})$th part of the whole feeder (go and return) resistance, the drop along R_1 will be $(\frac{1}{n})$th of the total drop. The voltmeter then if connected to one feeder measures $(\frac{1}{n})$th part of the bus-bar voltage less $(\frac{1}{n})$th part of the drop, *i.e.*, $(\frac{1}{n})$th part of the voltage existing at the far end of the feeder. If a number of feeders be simultaneously con-

nected to the same voltmeter, this latter will indicate the average of all the individual voltages. The connecting wires must, however, as already stated, have sufficient resistance (ρ) to avoid any appreciable interchange of current between the different feeder circuits.

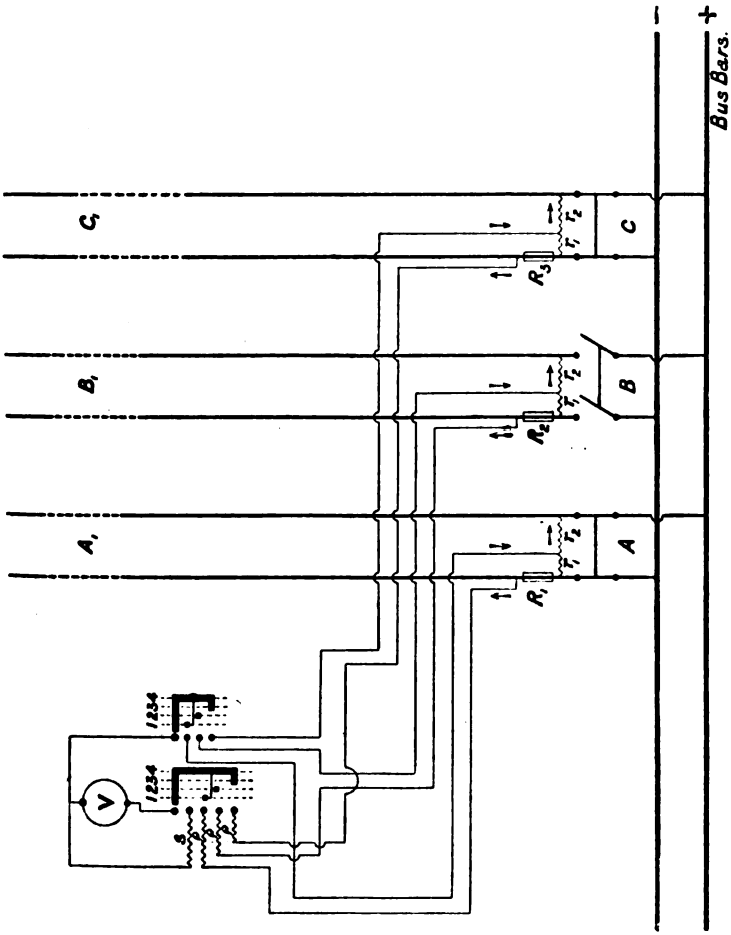

FIG. 2.

The action of the shunt s, which is necessary with the arrangement shown in Fig. 2, but not with that shown in Fig. 1, will be found fully explained in the analytical treatment of the subject.

It may here be mentioned that the writer, on subsequent investigation, found that particular cases of his method had

been anticipated by Mershon in America, and by Crompton and Ashley, and later by Heap, in England.[1]

Mershon's patents relate exclusively to alternating currents, since he bases them fundamentally on the use of either current or potential transformers, or both. Fig. 3 shows one of Mershon's arrangement, though many equivalent arrangements are illustrated in his patent specifications.

Mershon's object is to compensate the voltmeter not only for the ohmic but also for the inductive drop of the line, and his arrangement is only used in connection with single lines; *i.e.*, it corresponds to case (*a*), where the number of feeder circuits is unity.

As is evident from Fig. 3, the shunt resistance $r_1 + r_2$ of Fig. 1 is replaced by a potential transformer whose ratio

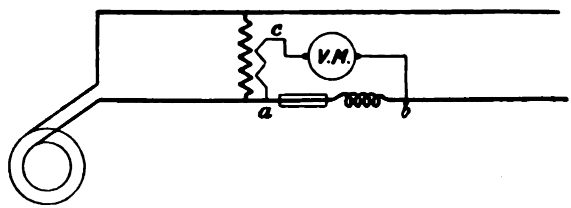

FIG. 3.

is $n:1$. Further a resistance and a self-induction are inserted in the line whose values are $(\frac{1}{n-1})$th times those of the line resistance and self-induction respectively.

Referring to Fig. 3, we see then that the drop from *a* to *b* will be $(\frac{1}{n})$th of the whole drop and in phase with it, whereas the secondary voltage of the transformer is $(\frac{1}{n})$th of the generator voltage, and if the terminals be correctly chosen in phase with it. Thus the voltage *b c*, or that measured by the instrument, is $(\frac{1}{n})$th of that existing at the end of the line.

The anticipations of Crompton and Ashley, and later by

[1] Mershon: American Patent 551,982; dated December 24, 1895.
" " " 571,839; " November 24, 1896.
Crompton and Ashley ... 6,695; " ... ... 1898.
Heap ... ... 8,348; " ... ... 1898.

Heap, are merely case (*a*), where the number of feeder circuits is unity, *i.e.*, they compensate the voltmeter for the drop of voltage in a single pair of feeders by using shunt and series resistances as explained. The diagram of connections for this simple case is shown in Fig. 4, and needs no further comments.

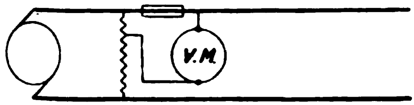

FIG. 4.

Neither Mershon, Crompton and Ashley, nor Heap, however, give any method for obtaining the average voltage at any desired group of feeding points, nor, with one exception referred to later on, is any method given in the above-mentioned patents applicable to case (*b*), *i.e.*, when unequal currents exist in the go and return feeders as in the case of three-wire systems and the like. This case, however, is just as important as the foregoing, owing to the extensive use now made of the three-wire system.

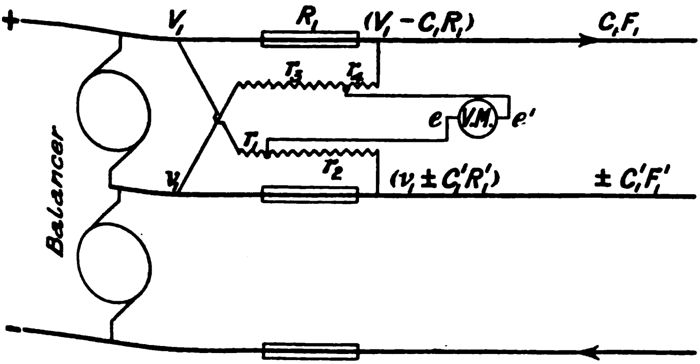

FIG. 5.

In such cases the voltage at the network between the neutral and each outer may be required to be known. The switchboard apparatus needed is very similar to that already described, the difference being that in this case series resistances must be inserted in *each* main, and the potential resistances are somewhat differently arranged.

Fig. 5 shows the arrangement as applied to but one set of feeders. The voltmeter V will then be compensated for the combined drop both in the outer and neutral mains with which it is connected. If the average voltage between, say, the positive outer and the neutral at several feeding points be required, the arrangement of multiple contact switch as in Fig. 2 may be employed.

The principle involved in this case is somewhat different to that of case (*a*), and may be best understood by comparison with a Wheatstone's bridge.

Fig. 6 may be considered as equivalent to Fig. 5 if we

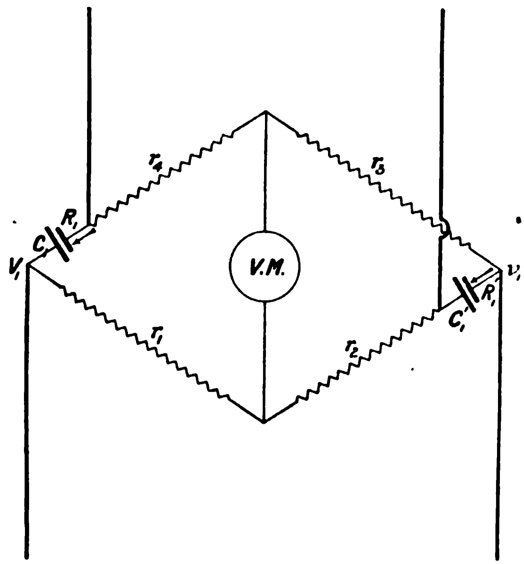

FIG. 6.

consider the potential differences called into play by the drop across R_1 and R'_1 as replaced by opposing E.M.Fs. If now the ratio arms of the Wheatstone's bridge be slightly out of balance, it is clear that the current through the voltmeter will be proportional to the expression $\{V_1 - v_1 - (\alpha\ C_1\ R_1 + \beta\ C'_1\ R'_1)\}$. Where α and β are numerics the value of which may be adjusted as desired by merely altering the resistance of the ratio arms. If, therefore, they be adjusted so that $\alpha\, R_1$ equals the resistance of the outer, and $\beta\, R'_1$ the resistance of the neutral, it is clear the voltmeter indications will be proportional to the voltage obtaining at the far end between outer and neutral.

With the device just described it is of utmost importance to select as sensitive a voltmeter as possible in order to minimise the losses which take place in the shunt resistances. In the latter portion of this communication this is shown to be the case, the following result being arrived at analytically :—

If the method be applied to a three-wire system with 400 volts between outers, and if the series resistances in the outer and neutral mains are as large as is at all practicable to make them (*e.g.*, the drop of volts along $R_1 = 0{\cdot}2$ volts and along $R'_1 = 0{\cdot}4$ volts with an average full load (the drop along the resistance R'_1 may be taken higher than along R_1 since the current in the former case is much less than in the latter, so that a larger drop does not necessarily imply a large loss of power), and if the voltmeter required $\frac{1}{100}$th ampere to give the full scale deflection, then the resistance of $(r_1 + r_2)$ and $(r_3 + r_4)$ could not well be more than 890 ohms. This would involve in them alone a continuous loss of nearly 90 watts. Instruments of the dead-beat suspended coil D'Arsonval type made up in switchboard form, with a needle swinging in a horizontal plane as in a Kelvin low-tension electrostatic voltmeter, would therefore be best for this purpose, for with suspended coil voltmeters of this description not only can the values of the resistances $(r_1 + r_2)$ and $(r_3 + r_4)$ be increased to 3,000 or 4,000 ohms, but the maximum drop of volts across R_1 and R'_1 may also be greatly reduced.

When employing this method for determining the average of several feeding-point voltages, a multiple contact switch as shown in Fig. 2 is necessary. It is also necessary to shunt the voltmeter by means of the resistance S, but the resistance ρ of the various connecting wires may be made as low as is convenient, since the resistances r_1 r_2 r_3 r_4 will themselves prevent any appreciable interchange of current between the various feeder circuits.

Fig. 7 shows a particular case where the voltage at the end of a set of three-wire feeders may be simply arrived at. The figure is a sufficient explanation of itself. It is, however, clear that this case is rarely applicable in practice.

In Heap's Patent 8,348 of 1898, instruments of the Weston type are described for use in three-wire circuits, where the moving member has two distinct coils and four terminals

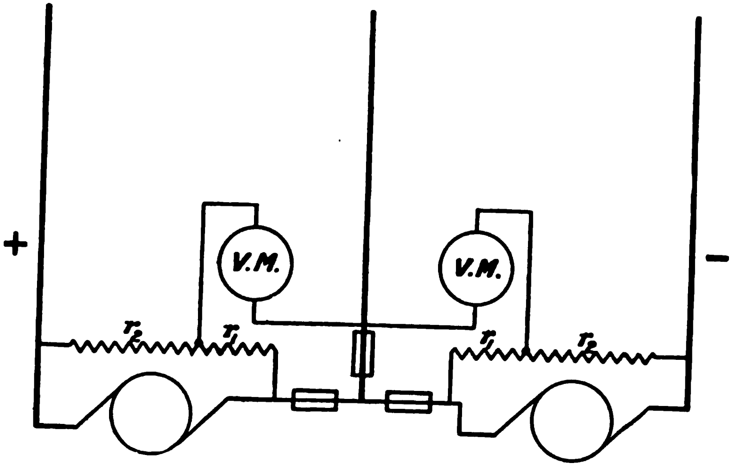

FIG. 7.

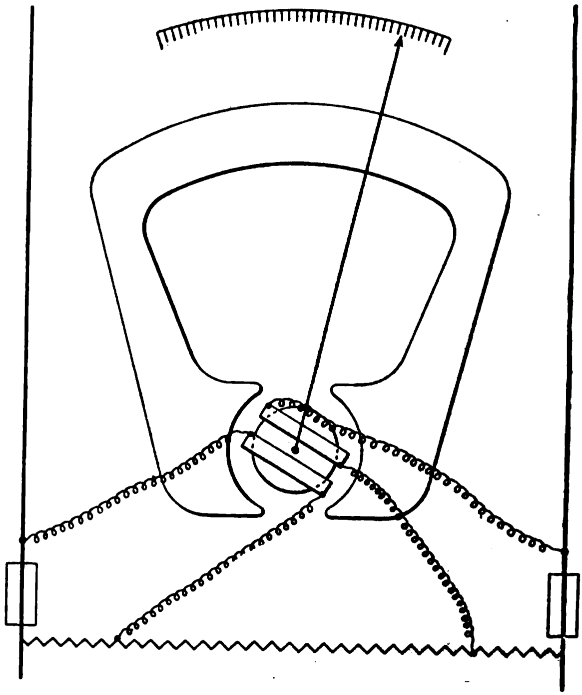

FIG. 8

as shown in Fig. 8. The great disadvantage of this arrangement is, of course, the difficulty of insulating the coils on the movable member from each other, the difference of potential being the full voltage between outer and neutral wire.

A further device is described, as shown in Fig. 9, with reference to instruments depending on the attraction of a small piece of iron. If these instruments be used at all, they may quite as readily be compounded with a few turns in series with the outer and neutral mains in accordance with the original scheme of Dr. Hopkinson. In any case,

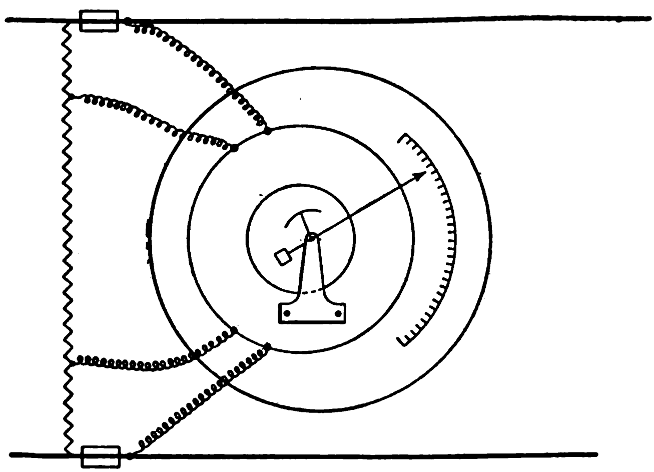

FIG. 9.

the device described above of Heap possesses the disadvantage that unless a large drop be allowed in the inserted resistances in the mains, the available voltage across the terminals of the voltmeter is altogether insufficient. For example, on a 250-volt circuit, if the series resistance caused an added drop of, say, 2 per cent. of the feeder drop, the available difference of potential for working the voltmeter would be only about 2·5 volts. With an instrument of the above type to be actuated by only 2·5 volts, a comparatively large current would be necessary, causing a relatively large watt-loss in the whole arrangement.

Case C.—This case, viz., the compensation for the ohmic and inductive drop in long alternate-current transmissions

lines has been very ingeniously handled by Mershon. As already intimated, Fig. 3 gives the pith of Mershon's arrangement, but in his American patents a considerable number of very pretty modifications are shown; but all of these, as he is careful to point out, depend upon the employment of potential or current transformers, or both.

The following method, therefore, which is quite independent of all transformers, not even necessitating one for the voltmeter, may be of interest.

In this instance not only must an extra resistance be inserted in the line, but similarly an extra self-induction, unless indeed a portion, say a $\frac{1}{300}$th part of resistance and self-induction of the line itself, be employed for the purpose by running back a pilot-wire to the station from a point on the line situated at a distance from the power-station equal to ($\frac{1}{300}$)th part of the whole length of the line.

To fix our ideas, let us consider a specific case where the line voltage is 30,000 volts, the line being 50 miles from end to end. At the station a 100-volt multicellular electrostatic voltmeter of the Kelvin type is employed, and connected as shown in Fig. 10. It would, of course, have to be thoroughly insulated from earth. k_1 and k_2 are condensers replacing the resistances r_1 and r_2 shown in Fig. 1. The condenser k_2 has a capacity approximately equal to the maximum capacity of the voltmeter, *i.e.*, the capacity between the fixed and moveable vanes, the latter being in the position they normally occupy when the voltmeter is indicating its maximum voltage. The capacity of the condenser k_2 is accordingly very small; it must, however, be capable of withstanding practically the full line voltage of 30,000 volts. The writer therefore proposes to employ for this condenser a slab of glass with pieces of tinfoil pasted on the two opposite surfaces, the slab being sufficiently thick to withstand the voltage, and the area of the tinfoil coatings being chosen to give a capacity approximately equal to the maximum capacity of the voltmeter. To prevent leakage and condensation on the edges of the slab, the whole might advantageously be immersed in a bath of special oil or be imbedded in a block of paraffin wax or other suitable dielectric.

The condenser k_1 must have a capacity nearly 300 times as great as that of k_2; since, however, the voltage across the

former will be of the order of 100 volts, it can readily be constructed in the usual way of sheets of tinfoil and mica, and will not be an expensive matter. It is important that the ratio of the capacities of $k_1 : k_2$ be maintained exactly, but it is not of any importance that the capacity of k_2 shall bear any very exact ratio to that of the voltmeter. Thus the voltmeter, if deranged, might be replaced by another of the same pattern, and the latter would indicate correctly. If a portion of the line itself be utilised, instead of inserting extra resistance and inductance a pilot-wire must be run back from a point one-third of a mile distant from the power house. This wire must be protected, of course, from the inductive action of the current in the line in a manner explained later on. One advantage in utilising a

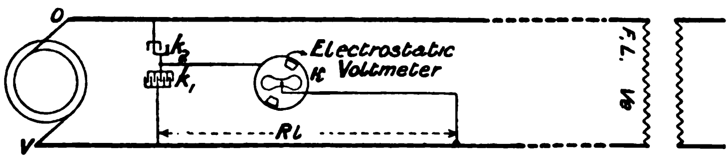

FIG. 10.

portion of the feeder itself instead of inserting extra resistances, etc, which may of course be done in this or any of the foregoing cases, is that no error is produced by a change of resistance of the line due to changes of atmospheric temperature.

We thus have a simple and inexpensive arrangement whereby a 100-volt electrostatic voltmeter may be arranged to measure directly the potential at the far end of a 30,000-volt line, the voltmeter being compensated for both ohmic and inductive effects of the line itself.

It is obvious that similar arrangements may be applied to many such useful purposes; *e.g.*, in the last case the voltmeter might be arranged to compensate not only for the line drop, but also for the drop due to both copper resistance and magnetic leakage in the transformer at the far end, and thus indicate the voltage at the low-tension terminals of the transformer irrespective of what kind of load may be connected to the same, *i.e.*, one possessing self-induction capacity or anything else.

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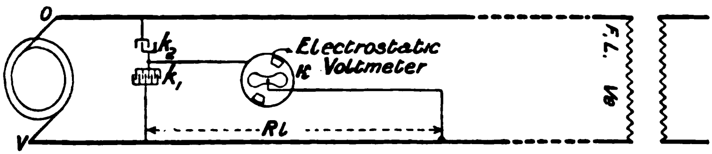

FIG. 10.

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The drop in the transformer might be exactly imitated by inserting in series in the circuit (now containing a perfect transformer with no drop) a definite self-induction and resistance. These might then be considered as forming part of the transmission line, and therefore by adjusting k_1, k_2, and the inserted resistance and self-induction, or possibly the position at which the pilot-wire is connected, the drop due to the extra resistance and self-induction, *i.e.*, the drop in the transformer at the far end of the line, may also be compensated for.

Analytical Investigation.

A simple and straightforward, though possibly a somewhat lengthy, method of dealing with this subject is to consider n feeder circuits (Fig. 11), where F_1, F_2, F_n, etc., represent the total (go and return) feeder resistances of the various circuits. At the station end the positive and negative feeders of each circuit are bridged over by resistances $r_1 + r_2$, and all the points, 1, 2, 3, etc., of these resistances are connected together and to one terminal of the voltmeter. The potential of this terminal is e. The resistance of the voltmeter is r, and the current flowing through it i. It is further shunted by a resistance s.

Let $V_1 v_1$, $V_2 v_2$, etc., be the potentials of the positive and negative feeders of the different circuits respectively, then it is easy to show that—

$$e = \frac{r_2}{r_1 + r_2} \cdot \frac{\Sigma(V_1 + V_2 + \ldots V_n)}{n} + \frac{r_1}{r_1 + r_2} \cdot \frac{\Sigma(v_1 + v_2 + \ldots v_n)}{n} + \frac{r_1 r_2}{r_1 + r_2} \cdot \frac{s + r}{s} \cdot \frac{i}{n} \quad \ldots \ldots \ldots \quad (1)$$

Let R_1, R_2, ... R_n be the series resistances inserted in the feeder circuits, and let the far end of each of these be connected by a wire whose resistance is ρ to the second terminal of the voltmeter. Calling the potential of this terminal e', we may write—

$$e' = \frac{\Sigma(V_1 + V_2 \ldots V_n)}{n} - \frac{\Sigma(C_1 R_1 + C_2 R_2 \ldots C_n R_n)}{n} - \rho \cdot \frac{s + r}{s} \cdot \frac{i}{n} \quad \ldots \ldots \quad (2)$$

where C_1, C_2, . . . C_n are the various feeder currents, which may be taken as identical with the currents flowing through R_1, R_2, etc., provided ρ be sufficiently large to prevent any appreciable interchange of current between the various feeders.

We have further—

$$e' - e = i\,r \quad . \; . \; . \; . \; . \; . \; . \quad (3)$$

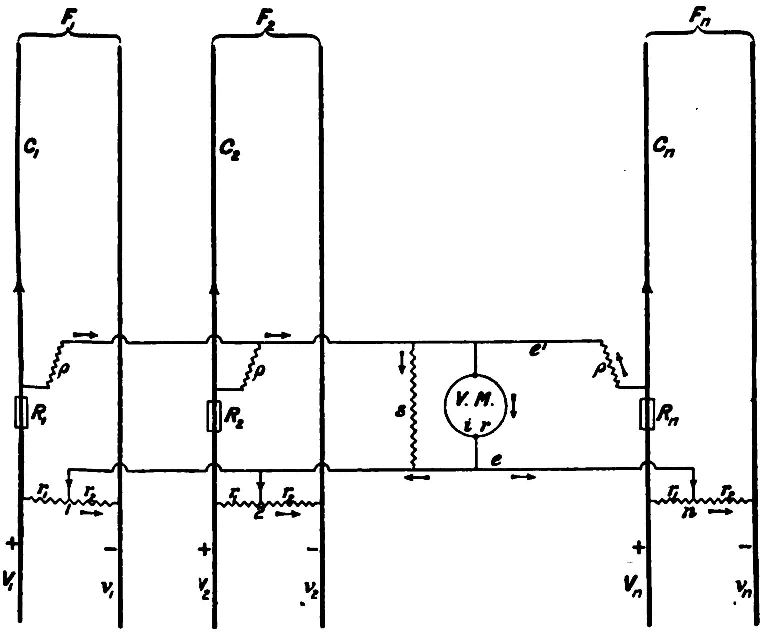

FIG. II.

Hence, eliminating e and e' we have—

$$i = \frac{\frac{1}{n}\Sigma\left(V_\kappa - v_\kappa - \frac{r_1 + r_2}{r_1} \,.\, C_\kappa R_\kappa\right)}{\left(\rho \,.\, \frac{r_1 + r_2}{r_1} + r_2\right)\frac{s + r}{s\,n} + r\left(\frac{r_1 + r_2}{r_1}\right)} \quad . \; . \; (4)$$

If

$$\frac{r_1 + r_2}{r_1} = \frac{R_1 + F_1}{R_1} = \frac{R_2 + F_2}{R_2} = \text{etc.},$$

the numerator of the above expression is merely the average

voltage existing at the far ends of all the feeder circuits. We will call this V_a. It is then clear that the current flowing through the voltmeter is proportional to V_a if any given number of feeder circuits be connected. The constant of the instrument, however, involves n; in order therefore to make the same calibration serve for all values of n, and to obtain the most sensitive arrangement, we must keep $\frac{s+r}{sn}$ equal to unity, in other words s must always equal $\frac{r}{n-1}$. This therefore is the function of the shunt s in Fig. 2, and if by means of the multiple contact switch, s be made to depend on n in the above manner, we have—

$$i = \frac{V_a}{r_2 + \frac{(\rho + r)(r_1 + r_2)}{r_1}}$$

If $n = 1$ we may make $\rho = o$ and $s = \infty$, *i.e.*, no shunt is required. This is the arrangement of Crompton and Ashley, and also of Heap.

The equation holding for the device represented in Fig. 1 is slightly different from the foregoing:—

We must insert in equation (1)

$$n = 1, \quad V = \frac{1}{n} \Sigma \left(V_1 + V_2 \ldots V_n \right), \quad o = \frac{1}{n} \Sigma \left(v_1 + v_2 + \ldots v_n \right)$$

and in equation (2) merely

$$V = \frac{1}{n} \Sigma \left(V_1 + V_2 \ldots V_n \right)$$

Combining (1) and (2), we have—

$$i = \frac{V_a}{\left(\frac{\rho}{n} \cdot \frac{r_1 + r_2}{r_1} + r_2 \right) \frac{s + r}{s} + \frac{r(r_1 + r_2)}{r_1}}.$$

Now in this case, if ρ be very small compared with r, we may say that i does not depend on n, hence s may be made ∞, *i.e.*, no shunt is required, and we have—

$$i = \frac{V_a}{r_2 + \frac{r(r_1 + r_2)}{r_1}}.$$

Applying the above results to an actual case, let $V = 200$, and let the current required by the voltmeter for maximum scale deflection, corresponding to (say) 220 volts, be 0·01 ampere, the resistance of the voltmeter being 60 ohms.

Let, further—

$$\frac{F_1}{R_1} = \frac{F_2}{R_2} = \text{etc.} = 99,$$

then we have—

$$r_2 = 16{,}000 \text{ ohms.}$$
$$r_1 = 161·6 \text{ ,,}$$

We may take it that the maximum feeder drop will not exceed 10 per cent., hence the maximum volt drop along R_1, R_2, etc., cannot be greater than 0·2 volt. If, therefore, $\rho = 0·75$ ohm, we may say that the interchange of current between any two feeders cannot be more than 0·13 ampere, or an amount which is quite inappreciable, and at the same time the maximum error introduced by the variation of the value of $\frac{\rho}{n}$ as n is varied cannot exceed $\frac{1}{5}$ of one per cent.

With the arrangement shown in Fig. 2, ρ must be much greater than heretofore assumed, for if one set of feeders be switched out, the voltage at the near end of the positive of the same might differ by as much as 20 volts from that of neighbouring positive feeders, and a serious interchange of current between them would occur if ρ were not of considerable magnitude. Since, however, from equation 4 it appears that no error whatever is produced by the variation of n, provided s is always equal to $\frac{r}{n-1}$, we may, if we like, take $\rho = 100$ ohms. In this case, taking the same constants for the voltmeter as before, r_2 will come out 6,000 ohms and r_1 60·6 ohms.

It has been assumed throughout the foregoing that the same current returns by the negative feeder as goes by the positive feeder of the same circuit; this will generally be true, unless indeed the resistances of the positive and negative feeders are different, or the problem is complicated by the fact that there are faults at different parts of the system. In such cases, however, where the outgoing current is of

different magnitude from the return current, the following arrangement might be employed, which moreover is particularly applicable to three-wire systems and such like.

To derive an expression for i in case (b)—see Fig. 5—we have from equation (1)—

$$e = \frac{r_2}{r_1 + r_2} \cdot \frac{\Sigma V_\kappa}{n} + \frac{r_1}{r_1 + r_2} \cdot \frac{\Sigma v_\kappa \pm C'_\kappa R'_\kappa}{n} + \frac{r_1 r_2}{r_1 + r_2} \cdot \frac{s + r}{s} \cdot \frac{i}{n} \quad . \; . \; . \; . \; . \; . \; . \quad (5)$$

To obtain e' we must substitute in this same equation—

e'	for	e	$V_\kappa - C_\kappa R_\kappa$	for	V_κ
r_4	„	r_1	v_κ	„	$v_\kappa \pm C'_\kappa R'_\kappa$
r_3	„	r_2	$-i$	„	i

and we may further write $r_1 + r_2 = r_3 + r_4$,

hence—

$$e' = \frac{r_3}{r_1 + r_2} \cdot \frac{\Sigma V_\kappa - C_\kappa R_\kappa}{n} + \frac{r_4}{r_1 + r_2} \cdot \frac{\Sigma v_\kappa}{n} - \frac{r_3 r_4}{r_1 + r_2} \cdot \frac{s + r}{s} \cdot \frac{i}{n} \quad . \; . \; . \; . \; . \; . \; . \quad (6)$$

Combining (3), (5), and (6) we get—

$$i = \frac{\frac{i}{n} \Sigma \left(V_\kappa - v_\kappa - C_\kappa (R_\kappa + F_\kappa) \mp C'_\kappa (R'_\kappa + F'_\kappa \right)}{(p r_4 + q r_2) \frac{s + r}{s n} + \frac{r(r_1 + r_2)}{r_3 - r_2}} \; . \quad (7)$$

where

$$\frac{r_3}{r_3 - r_2} = 1 + \frac{F_1}{R_1} = 1 + \frac{F_2}{R_2} = \text{etc.} = p,$$

and

$$\frac{r_1}{r_3 - r_2} = 1 + \frac{F_1'}{R_1'} + 1 \frac{F_2}{R_2'} = \text{etc.} = q$$

Now the numerator in (7) is the average voltage obtaining at all the far ends of the feeder circuits between the outers F_1, F_2, etc., and the neutrals F_1', F_2', etc. Call this average voltage, as before, V_a.

If, then, we again, by means of the multiple contact switch, keep $\frac{s + r}{s n}$ equal to unity, we have for case (b)—

$$i = \frac{V_a}{p\,r_4 + q\,r_2 + \dfrac{r\,(r_1 + r_2)}{r_3 - r_2}},$$

from which the necessary values for r_1, r_2, r_3, and r_4 are calculable for any given instance.

The last case is that of (*c*), Fig. 10. We can readily derive the equation for the voltage existing across the voltmeter (which may be designated v') from equation (4), by writing:—

$n = 1$	$R + l\theta$ for R_1	$\dfrac{1}{k_2\,\theta}$ for r_2
$s = \infty$		
$\rho = 0$		
$v = 0$	$\dfrac{1}{k_1\,\theta}$ " r_1	$\dfrac{1}{\kappa\,\theta}$ " r;

where R and l are the resistance and self-induction respectively of that portion of the line spanned by the pilot-wire, κ is the capacity of the voltmeter, this being a function of the position of the movable vanes, and θ represents the operator $\dfrac{d}{dt}$.

We have then—

$$v' = \frac{i}{\kappa\theta} = \frac{V - \dfrac{k_1 + k_2}{k_2} \cdot \Big(R + l\theta\Big)C}{\dfrac{\kappa + k_1 + k_2}{k_2}}.$$

If—

$$\frac{k_1 + k_2}{k_2} = \frac{F}{R} = \frac{L}{l},$$

the numerator of the above expression represents the voltage obtaining at the end of the line. Call this V_e.

As already explained, k_2 may advantageously be made about equal to the maximum value of κ, in which case, owing to the comparatively large value of k_1, we may write with great accuracy—

$$v' = \frac{k_2}{k_1 + k_2} \cdot V_e.$$

It has been pointed out in the previous part of this paper that it is necessary to shield the pilot-wire from the inductive action of the line.

If the line be a single-phase one carried overhead, it will be simple to place the pilot-wire symmetrically with regard to the two-line wires, in which case all inductive effects will be obviated.

If the line be an overhead three-phase one, it is not always possible to place the pilot-wire in a symmetrical position with regard to all three-line wires. The inductive action may, however, be neutralised by running the pilot-

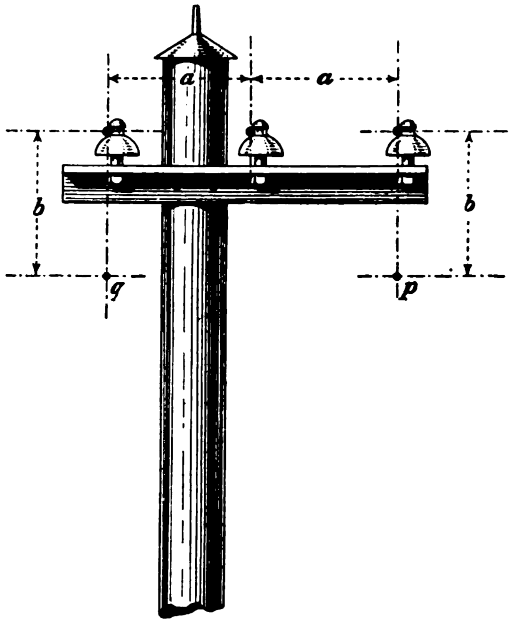

FIG. 12.

wire for *part* of the distance nearer the one or other of the lines. Thus, if the three-line wires be carried in a row (see Fig. 12) and a pilot-wire be run for a total distance of 500 yards from the station, it might be located for 250 yards in position p, and for the remaining 250 yards in position q. The inductive action of each line wire on the pilot-wire depends on the logarithm of the reciprocal of the distance between them plus a constant, which latter is the same for all the line wires.

If, therefore, we adjust matters so that

$$\frac{1}{2}\log.\left(\frac{1}{b}\right) + \frac{1}{2}\log.\left(\frac{1}{\sqrt{4a^2 + b^2}}\right) = \log.\left(\frac{1}{\sqrt{a^2 + b_2}}\right),$$

or

$$b = \frac{1}{\sqrt{2}} a,$$

the inductive action of each line wire on the pilot-wire will be the same, and since the total current flowing in the three-line wires at every instant is zero, the total inductive effect will likewise be zero.

With other arrangements of the line wires, corresponding modifications of the positions of the pilot-wire will be requisite.

APPENDIX.

(*Received February 23rd, 1901.*)

It is interesting to note that if the three lines of a three-phase transmission be arranged as shown in Fig. 12, the induced E.M.F. in each line due to the self-induction of its own current and the mutual induction of the currents in the other wires is not the same in each case, and consequently, in compensating for the line drop, this should be taken into account.

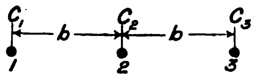

FIG. 1.

This inequality may readily be shown to exist thus:—Neglecting the magnetic induction within the line wires themselves, the total induction in air between two line wires at distance apart b and of radius a, per unit length of line

$$= \frac{4C}{10} \log \frac{b}{a}$$

where C = current in ampere in line. We may take therefore $\frac{2C}{10} \log \frac{b}{a}$ as the total induction cut by each wire, this being the sum of its own self-induced lines, and of those induced by its neighbour which it has cut. For the sake of brevity, this will here be called the inductive effect on the one-line wire.

Since the sum of the currents in the outers equals at every instant the current in the middle wire of the three-phase line, the inductive effect on the middle wire will be $\frac{2C_2}{10} \log \frac{b}{a}$ where C_2 is the instantaneous value of the current, it being quite immaterial whether all the return current be concentrated at one point or not, provided it all be at distance b from the line in question. (The inductive effect as defined above on *2* would be unaltered even though the return conductor were spread out as a thin sheath concentric with *2* and of radius b.)

The inductive effect on lines 1 and 3 respectively is per unit length :—

$$\frac{2}{10}\left\{C_1 \log \frac{1}{a} + C_2 \log \frac{1}{b} + C_3 \log \frac{1}{2b}\right\}$$

$$\frac{2}{10}\left\{C_1 \log \frac{1}{2b} + C_2 \log \frac{1}{b} + C_3 \log \frac{1}{a}\right\}$$

But $\left(\frac{2}{10}\log a\right)\left(C_1 + C_2 + C_3\right) = 0$, adding this in each case we have

$$\frac{2}{10}\left\{C_2 \log \frac{a}{b} + C_3 \log \frac{a}{b} - C_3 \log 2\right\}$$

$$\frac{2}{10}\left\{C_2 \log \frac{a}{b} + C_1 \log \frac{a}{b} - C_1 \log 2\right\}$$

These we may write as :—

$$\frac{2}{10}\left\{C_1 \log \frac{b}{a} - C_3 \log 2\right\}$$

$$\frac{2}{10}\left\{C_3 \log \frac{b}{a} - C_1 \log 2\right\}$$

and the inductive effect on line 2 is as above

$$\frac{2}{10}\left\{C_2 \log \frac{b}{a}\right\}$$

In an actual case let $\frac{b}{a} = 100$, and remembering that the induced E.M.F.'s lag 90° behind the currents which induce them, we may construct the vector diagrams for the induced E.M.F.'s in the three-line wires as follows :

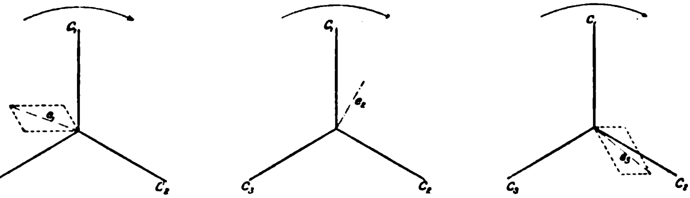

Fig. 2.

We see, then, that in the case of line 1, an E.M.F. is injected into the line 30° behind the current; in line 3 an equal E.M.F. appears 150° behind the current, that is, to say, that 3 and 1 are acting as the primary and secondary of a transformer power disappearing from the one and appearing in the other line. The amount of this injected E.M.F. is 15 per cent of c_2, that is in the above case, the relative values of the induced E.M.F.'s would be as 2·16 : 2 : 2·16 respectively for the lines 1, 2 and 3. In extra high tension transmission lines it is quite possible for the inductive effect to exceed the ohmic drop, so that the above differences may be worth considering.

The voltmeter in such a case would be arranged to measure the voltage between one pole and the neutral point compensating for the mean drop along the three-line wires, and the scale would be calibrated to read 1·732 this voltage.

The neutral point would be obtained by means of two suitable choking coils in the usual way, connecting one to the centre point of the winding of the other, as in the diagram.

It is further interesting to inquire into the magnitude of the inductive effect of a line upon a pilot wire which is not shielded.

As an example, assume 3 to be a pilot wire and 1 and 2 the go and return conductors of the circuit.

The inductive effect on 3 will be $\frac{2}{10}$ C log 2 and on 1 and 2 $\frac{2}{10}$ C log $\frac{b}{a}$ if C = line current. If $\frac{b}{a} = 100$ as before, the induced E.M.F. in the pilot wire will be 15 per cent. of the induced E.M.F. in each line wire. As stated above, this latter is sometimes greater than the ohmic drop, so that the effect on the pilot wire is seen to be of considerable magnitude; this is more especially the case where the pilot wire is worked at a reduced pressure by means of step-down transformers at the far end of the line, which is often the case owing to the liability of thin aerial lines to break, and the danger which would thus be introduced.

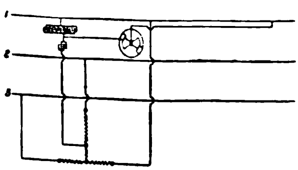

FIG. 3.

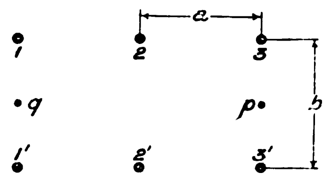

FIG. 4.

It is not always possible to shield the pilot wire from the inductive action of a multiplicity of line wires. In such a case it would be advantageous to change over the positions of the various wires periodically, so as to neutralise their effects.

In the case of two three-phrase circuits carried as in the fig., the pilot wire should be taken for half its distance in position p and the remaining distance in position q where $b = a\sqrt{2}$.

The CHAIRMAN, in opening the discussion, remarked that the paper was not only a learned one from an analytical point of view, but also an exceedingly important paper from a practical point of view. Later, in the discussion he asked Mr. Field—(1) to give some relative statements as to the amount of energy wasted in the series resistances R_1, R_2, R_3, etc., and (2) to make it clear if these resistances were not exactly $\frac{1}{n}$th of the feeder resistances, whether or not the voltmeter needed recalibration in the central station. The Chairman.

Professor A. JAMIESON: Mr. Field has been rather lax in the phraseology of the first part of his paper, but he has made up for this defect by giving us a series of well-arranged and indexed diagrams, together with a final clear analytical investigation. Professor Jamieson.

The chief object which the author had in view was to ascertain the drop in pressure along live feeders without using pilot-wires, and thus

Professor Jamieson.

not only to save their first cost and upkeep, but also to avoid being troubled by their possible defective insulation or continuity. He puts down the first cost of twin pilot-wires at £90 per mile. I think that this may be taken as a maximum value, since the trenches must be opened for the feeder-troughs or pipes whether pilot-wires are put down or omitted. Perhaps Mr. Field will state in his reply how he arrived at this price.

The average potential at the ends of any group of feeders might be obtained from the switchboard ends of the corresponding pilot-wires quite as easily as by the methods explained in the paper. There is, however, one disadvantage which Mr. Field's system has, when compared with the use of pilot-wires, viz., their employment (if sound) in localising faults in the feeders by means of "loop tests." And, moreover, he introduces a constant loss of power by the permanent insertion of the series-resistances R_1, R_2, R_3, etc. (see Figs, 1, 2, etc.), unless he can employ them as the feeder "fuse-wires," or for the lightning protector coils, or for the automatic switch coils. For example, suppose the current conveyed by each of these several resistances to be 1,000 amperes with a difference of potential between their ends of only 0·2 volt (as assumed in the paper), then the continuous loss of power will be $(1{,}000 \times 0{\cdot}2) =$ 200 watts for each inserted resistance. This quantity, when added to the losses $(r_1 + r_2)$ may thus amount to about $\frac{1}{3}$ H.P. at the switchboard or, say, $\frac{1}{2}$ H.P. in the boiler. The annual value of this loss would go far to pay interest and depreciation upon ordinary pilot-wires.

Mr. Field's ingenious methods of obtaining the average voltage at the ends of a group of feeders may no doubt satisfy the Board of Trade authorities, who demand statements of such averages in the station log-sheets, but great care must be taken that switchboard attendants do not place too much reliance upon such averages. One consumer or district may be supplied at 10 per cent. more than the normal voltage, whilst another is receiving 10 per cent. less than the normal. The attendant when reading the voltmeter in contact with the average terminal would consequently find that the mean voltage coincided with the required pressure. This would no doubt please him, and if he were lazy and not very particular, he would not trouble to ascertain what the respective voltages were at the end of each feeder.

The method (see Fig. 1) of ascertaining the voltage at the far end of a line of known resistance, by taking the potential difference between the ends of another known resistance placed in circuit with the former at its home end, is not new. I have frequently used this test since 1872, and I believe that it was first devised by Mr. Latimer Clark and improved by Professor Fleeming Jenkin.[1] Fig. 2, for obtaining averages, is, however, new to me, and I have much pleasure in congratulating Mr. Field upon the devices and their explanations as illustrated by Figs. 4, 5, 6, and 10. The latter is especially neat and interesting, although the substitution of condensers for resistances is by no means new. Their use and interchangeability in the case of the bridge-arms of artificial lines for working submarine cables upon

[1] See Munro and Jamieson's *Pocket-Book of Electrical Rules and Tables.*

Professor Jamieson.

the duplex principle has been employed for nearly a quarter of a century. Their application, however, to very high alternate current voltages is one of the difficult experiments upon which we should have been glad to have had some practical results. Perhaps Mr. Field may soon be able to bring before us data of actual tests and thus add to the value of his present paper.

Mr. McWhirter.

Mr. WILLIAM MCWHIRTER: Mr. Field has written a splendid paper and has shown how to carry out an important test in a very elegant, simple, and economical manner. Never having been a Central Station engineer, I have not been in a position to discover all the beauties which these engineers have found in the Weston Moving Coil Voltmeter. No doubt, owing to the great sensibility of this type of instrument and to the low power therefore required to operate it, together with the proportionality of the scale divisions and its *supposed* extreme constancy, this instrument has made many friends. To these qualities must be added its freedom from external magnetic fields, from which it is usually *supposed* to have perfect immunity. The simpler and cheaper, yet equally useful, electro-magnetic voltmeter has therefore been relegated to a position of obscurity, and the individual who attempts to check the voltage of any installation by such means runs a risk of being driven from the society of all self-respecting electricians. Yet there are hundreds of thousands of those unassuming instruments in daily use doing good work. Those who have been able to watch the evolution of this type of instrument since 1878, when the electric lighting at the Paris Exhibition showed the need for it, must have often asked, "Have we yet approached finality?" Almost the first attempt to supply the demand for such measuring instruments was met by Deprez, who introduced an instrument of the permanent-magnet type. We had next the very excellent but certainly awkward set of dynamometers by Siemens Brothers, where the value of current or pressure could be easily ascertained by twisting the torsion-head until the moving coil reached zero. When, reading the angle of torsion in degrees, and finding its square root and multiplying by a five-figure constant, the amperes or volts were at once found. So beautiful and simple an instrument was not, however, received as it should have been, and I have known engineers in charge of lighting in those early days, and drawing the splendid salaries of from 18s. to 22s. per week, object to the use of the instruments.

It always seemed strange to me that only one man up to that time had made instruments to read direct in amperes, or, rather, at the time to which I refer, in webers and volts, and that was Mr. J. T. Sprague, of Birmingham. I would like, however, to warn central-station engineers not to take too much for granted about Weston moving-coil meters, not to be sure the scale divisions are strictly proportional, nor to assume the *constancy* of magnetic field, or to take it for granted that these meters are *not* affected by external magnetic fields. I have proved over and over again that every one of these assumptions is in error. Now that shielded electro-magnetic volts and ammeters are obtainable where less than two watts are used upon a circuit of 100 volts, where the tempera-

Mr McWhirter.

ture coefficient is *nil*, where the scale error is under 1 per cent. and absolutely constant, and where magnetic-field errors do not exist, they are worthy of further attention, and should not be lightly abandoned. Further, such instruments can be calibrated to read correctly upon either continuous- or alternating-circuits as required, and are therefore most suitable for use in the arrangement of Hopkinson, which, from its simplicity, will be very hard to supplant.

Mr. Field.

Mr. M. B. FIELD in reply said: Professor Jamieson commented at considerable length on the phraseology used by me in the opening sentences of the paper. I have no doubt that this might be much improved, but provided the paper represents correctly the technical points I wished to bring before you, I think it hardly worth while to waste further time in discussing the point. Professor Jamieson seems to think that measuring the "average voltage" over a network is useless. I admit it does not give all the information required, but then, by the methods I have described to-night, not only the average, but also the individual feeding-point voltages can be determined. In such a case I think that a little consideration will show that the information obtained *is* of distinct advantage. The price of £90 per mile of twin pilot-wire has been thought excessive. This, however, was not a guess-work figure: it was the actual figure for a two-core paper-insulated, lead-covered cable capable of withstanding 1,000 volts between cores, or between cores and lead, and includes drawing in and jointing. It is by no means a high price. Professor Jamieson tells us that the method I have described for compensating voltmeters as due to Crompton and Ashley did not originate with them. I believe, however, they took out the original patents. Answering the remarks on the applicability of the methods described to power and traction schemes, I would say that an exact regulation of the feeding-point voltage on tramway systems is not at all essential. The reference made in the paper to power systems applies to such as include the driving of motors of cotton-spinning machinery and such like where an exact and constant speed is of the utmost importance. Professor Jamieson further remarked that the different temperature coefficients of the series resistances R, R_1, etc., and of the line would produce errors. It is evident, however, that since we are compensating the voltmeter for a quantity of, say, not more than 10 per cent. of the total measurement, a small percentage of this compensation becomes negligible. If we want to be very exact we can dispense with R, R_1, etc., altogether by using a portion of the cable itself and running a pilot-wire back, say, from the first junction-box along the route. Regarding the losses that occur in R_1, R_2, R_3, etc., I mentioned in the paper that for heavy currents the drop along these resistances might be reduced to, say, 0·1 volt at full load. This is about the order of loss in the ordinary ammeter shunts used for switchboards, and consequently the feeder ammeter shunts might quite well be employed for the compensating voltmeters (adjusting r_1 and r_2 suitably), so that no added loss by the inserted resistances would then occur.

I do not understand the difficulty of making a condenser to withstand a pressure of 30,000 volts in the manner I have described. There

is certainly no difficulty in making porcelain insulators to withstand this voltage, and if a correspondingly thick slab be used for the condenser no difficulty should be experienced. Mr. Fiel

Mr. McWhirter spoke about my preference for Weston instruments. I think I pointed out that the methods dealt with in the paper are applicable using any type of sensitive instruments without constructional modifications of any kind. All that is necessary is a readjustment of resistances.

Replying to Professor Maclean, I would say that if R, R_{1}, etc., are not exactly right, no very great error is introduced. The voltmeter readings will merely compensate for the drop in a line a little longer or a little shorter than the actual one. It is not at all necessary to calibrate the instruments *in situ*. A spurious line circuit having the correct feeder-resistance is made up in the laboratory and connected to the instrument, which is easily calibrated under these conditions and the series resistances perfectly adjusted. The series resistances are precisely similar to those supplied with Weston ammeters, and therefore do not involve any greater energy losses than do these ammeters which are in very common use.

ORIGINAL COMMUNICATION.

NOTE ON RESONANCE WITH ALTERNATING CURRENTS.

By ALEXANDER RUSSELL, M.A., Member.

Although the effects of resonance in alternating current circuits have been well known for many years, it is only recently that it has been proposed to utilise these effects for testing and other purposes. Rosa and Smith[1] have utilised the rise of pressure due to resonance to measure more accurately the losses in a condenser. Lodge[2] makes use of it in his system of space telegraphy. Duddell has recently utilised a resonant circuit to get high frequency alternating

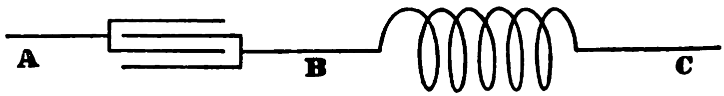

FIG. 1.

currents from the direct current arc between hard carbons. It has often been proposed also to utilise the resonance of currents in divided circuits, so as to raise the power-factor of the mains. It is therefore of importance that electricians should have clear ideas on this subject.

The sine curve theory is fairly satisfactory when only used as a rough guide to what happens in practice, but there are many important cases where phenomena happen which it completely fails to explain. In what follows I have attempted to fill up this gap in the theory mainly by considering numerical examples to show what we might expect when the wave is not shaped like a sine curve.

Consider an inductive coil (Fig. 1) in series with a condenser, and suppose that an alternating P.D. is applied to the terminals A and C. If the wave of P.D. be sine shaped, then it is easy to find the P.D.'s between A and B and be-

[1] *Phys. Rev.* 8. pp. 1–20, 1899; *Science Abstracts*, vol. ii., p. 243.
[2] *Journal of the Institution of Electrical Engineers*, vol. xxvii., p. 799.

tween B and C. Let the coil have a resistance R (ohms) and an inductance L (henries) and let the capacity of the condenser be K (farads). Now, by a well-known rule, we can replace the condenser by a coil whose resistance is zero and self-inductance

$$\frac{1}{K(2\pi f)^2}$$

where f is the frequency of the alternating current. Hence if C be the current and V, V_1 and V_2 the P.D.'s between A and C, A and B, and B and C respectively, then by the ordinary impedance formula,

$$C^2 = \frac{V^2}{R^2 + (2\pi f)^2 \left\{L - \frac{1}{K(2\pi f)^2}\right\}^2}$$

$$= \frac{V_1^2}{\frac{1}{(2\pi f)^2 K^2}}$$

$$= \frac{V_2^2}{R^2 + (2\pi f)^2 L^2}$$

Hence V_1 and V_2 are found in terms of V.

Resonance occurs when

$$L K (2\pi f)^2 = 1$$

In this case

$$V_1 = \frac{2\pi f L}{R} V$$

$$= \frac{1}{2\pi f K R} V$$

$$V_2 = \frac{\left\{R^2 + (2\pi f)^2 L^2\right\}^{\frac{1}{2}}}{R} V$$

In this case V equals C R and the power factor is unity.

When the applied P.D. wave is not sine shaped the formulæ become very unwieldy. Instead, however, of solving this problem, we have considered the much simpler case of how the pressures across the condenser and choking coil terminals vary with the shape of the current wave. We are thus enabled to utilise some of the results given in the *Journal*, vol. xxix., p. 154.

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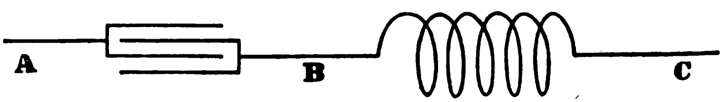

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where f is the frequency of the alternating current. Hence if C be the current and V, V_1 and V_2 the P.D.'s between A and C, A and B, and B and C respectively, then by the ordinary impedance formula,

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Hence V_1 and V_2 are found in terms of V.

Resonance occurs when

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In this case

$$V_1 = \frac{2\pi f L}{R} V$$

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In this case V equals C R and the power factor is unity.

When the applied P.D. wave is not sine shaped the formulæ become very unwieldy. Instead, however, of solving this problem, we have considered the much simpler case of how the pressures across the condenser and choking coil terminals vary with the shape of the current wave. We are thus enabled to utilise some of the results given in the *Journal*, vol. xxix., p. 154.

Resonance of E.M.F's.

Let e, e_1 and e_2 be the instantaneous values of the volts between A and C, A and B, and B and C respectively, and let i be the instantaneous value of the current, then—

$$e = \mathrm{R}\,i + e_1 + e_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$e_1 = \frac{\int i\,dt}{\mathrm{K}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$e_2 = \mathrm{L}\frac{di}{dt} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Now if we suppose that there is no loss in either the condenser or the choking coil, then by squaring (1) and taking mean values we get—

$$\mathrm{V}^2 = \mathrm{R}^2\,\mathrm{C}^2 + \mathrm{V}_1^2 + \mathrm{V}_2^2 + 2\,\mathrm{V}_1\,\mathrm{V}_2 \cos\phi \quad . \quad . \quad (4)$$

where C is the effective value of i and ϕ is the phase difference between e_1 and e_2.

By definition—

$$\cos\phi = \frac{\frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} e_1\,e_2\,dt}{\mathrm{V}_1\,\mathrm{V}_2}$$

From (2) and (3)—

$$\frac{1}{\mathrm{T}}\int_0^{\mathrm{T}} e_1\,e_2\,dt = \frac{\mathrm{K\,L}}{\mathrm{T}}\int_0^{\mathrm{T}} e_1\frac{d^2 e_1}{dt^2}\,dt$$

$$= \frac{\mathrm{K\,L}}{\mathrm{T}}\left.\overline{e_1\frac{d\,e_1}{dt}}\right|_0^{\mathrm{T}} - \frac{\mathrm{K\,L}}{\mathrm{T}}\int_0^{\mathrm{T}}\left(\frac{d\,e_1}{dt}\right)^2 dt$$

$$= -\frac{\mathrm{L\,C}^2}{\mathrm{K}}$$

$$\therefore\ \operatorname{Cos}\phi = -\frac{\mathrm{L\,C}^2}{\mathrm{K\,V}_1\,\mathrm{V}_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Now the relations between V_1 and C and between V_2 and C can be expressed as follows:—

$$\mathrm{C} = \alpha\,\mathrm{V}_1\,\mathrm{K}\,f \text{ and } \mathrm{C} = \frac{\mathrm{V}_2}{\beta\,\mathrm{L}f}$$

where α and β are constants that depend on the shape of

the current wave. Substituting these values of V_1 and V_2 in (5) we find that—

$$\cos\phi = -\frac{\alpha}{\beta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Hence substituting in (4)—

$$\frac{V^2}{C^2} = R^2 + \frac{1}{\alpha^2 K^2 f^2} + \beta^2 L^2 f^2 - 2\frac{L}{K} \quad . \quad . \quad . \quad (7)$$

This is the formula that gives us the impedance of the circuit A C (Fig. 1) when we know the shape of the current wave.

Numerical Examples.

For a sine curve $\alpha = \beta = 2\pi$ and ϕ is 180°.

For a parabolic current wave $\alpha = 2\sqrt{\frac{168}{17}}$, $\beta = \sqrt{40}$ and $\phi = 173° 46'$.

For a triangular current wave $\alpha = \sqrt{40}$, $\beta = \sqrt{48}$ and $\phi = 155° 54'$.

In (7) if we suppose K infinite it is the same as short circuiting the condenser, and we find the following expressions for the impedance I of an inductive coil (R, L).

For a parabolic current wave—

$$I^2 = R^2 + 1{\cdot}013\,(2\pi f L)^2$$

For a triangular current wave—

$$I^2 = R^2 + 1{\cdot}216\,(2\pi f L)^2$$

It is to be noted, however, that when the shape of the applied P.D. wave is fixed, the impedance can only be expressed in the form $\sqrt{R^2 + \gamma(2\pi f L)^2}$ where γ is a constant in a special case. In general it is a very complicated function of R, L and F.[1]

When the circuit (Fig. 1) is adjusted for resonance

$$(2\pi f)^2 L K = 1$$

In this case (7) becomes—

$$I^2 = R^2 + \left(\frac{4\pi^2}{\alpha^2} + \frac{\beta^2}{4\pi^2} - 2\right)(2\pi f L)^2$$

[1] *The Electrical Review*, vol. xlv. p. 744, "The Current Produced in an Inductive Coil by a Parabolic Wave of E.M.F."

For a parabolic current—

$$I^2 = R^2 + 0{\cdot}0119\,(2\,\pi f L)^2$$

For a triangular current—

$$I^2 = R^2 + 0{\cdot}2028\,(2\,\pi f L)^2$$

It is easy to see, geometrically, the values that V_1 and V_2 can have for a given applied voltage, and for a given shape of the current wave. In order to avoid solid geometry we will suppose that the resistance of the circuit is zero. In Fig. 2, if O A be the vector representing the condenser voltage, and O B represent the choking coil voltage, then the diagonal O C of the parallelogram constructed on them as adjacent sides gives the effective value of the applied voltage. The larger the angle B O A, that is, the more nearly the current wave approaches the sine curve in shape,

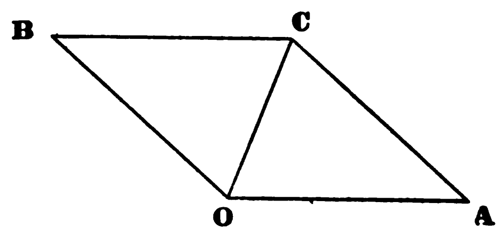


FIG. 2.

the smaller is the ratio of the resultant to its components, and hence the larger are the effects due to resonance.

Suppose (Fig. 3) that O P represents the magnitude of the voltage applied to the circuit shown in Fig. 1. Suppose also that the shape of the voltage wave is altered as the capacity or the inductance is altered, so that the current wave has always the same shape, then the condenser P.D. vectors can be measured along O A and the choking coil P.D. vectors along O B, the angle B O A remaining constant. If P R and P L be parallel to O B and O A respectively, then O R will be the condenser voltage and O L the choking coil voltage corresponding to the applied voltage O P.

Suppose that the voltage applied to the circuit is kept constant, then the locus of P is a circle. When the capacity is zero P is on O A. As the capacity increases, the

P.D. across the terminals of the condenser increases and attains its maximum value O S when the angle Q O B is a right angle. In this case

$$V_2 = - V_1 \cos \phi$$
$$\therefore K L (\beta f)^2 = 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Again, the choking coil voltage V_2 attains its maximum value when the angle A O S is a right angle, and in this case—

$$K L (\alpha f)^2 = 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The maximum value of either V_1 or V_2 is—

$$\frac{V}{\sin \phi} \ i.e. \ V \frac{\beta}{\sqrt{\beta^2 - \alpha^2}}.$$

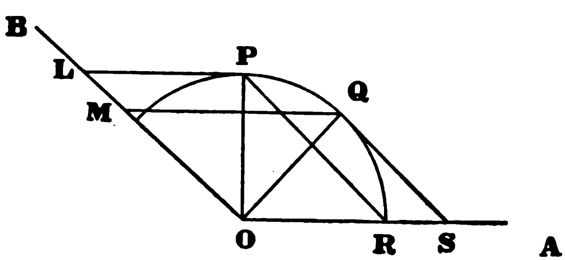


FIG. 3.

Substituting in this formula the values of α and β given above for parabolic and triangular waves, we find that for a parabolic current wave the maximum possible value of the condenser voltage is 9·22 V, where V is the applied voltage. Similarly for a triangular current wave the maximum value of the condenser voltage is 2·45 V.

For very distorted waves then it will be seen that the danger of getting excessive voltages from resonance is not nearly as great as for approximate sine waves.

A resonant circuit can only have a power-factor of unity when the shape of the applied P.D. wave is a sine curve.

It is proved in the *Electrician* for Nov. 3, 1899, p. 49, that the power-factor of a circuit can only be unity when $\frac{e}{i}$ is constant at every instant. If the resistance of the

circuit is constant then this ratio equals R, and hence from (1), (2), and (3)

$$L\frac{di}{dt} + \frac{\int i\,dt}{K} = 0$$

$$\therefore\ i = A \sin\left(\frac{2\pi t}{T} + B\right)$$

where A and B are constants and T equals $2\pi\sqrt{LK}$. Hence since $e = R\,i$ the applied P.D. wave is also a sine curve.

Since

$$C = a V_1 K f = \frac{V_2}{\beta L f}$$

$$\therefore \frac{V_1}{V_2} K L (2\pi f)^2 = \frac{4\pi^2}{a\beta}$$

Now when the circuit is adjusted for resonance

$$K L (2\pi f)^2 = 1$$

Hence

$$\frac{V_1}{V_2} = \frac{4\pi^2}{a\beta} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

The ratio of V_1 to V_2 is a measure of how much the current wave differs from a sine wave. If this ratio equals unity, the current wave is a sine curve, and the smaller the ratio the more distorted is the current wave.

In Fig. 4 we have supposed that the curve (I), which is a parabola, represents the shape of the wave of current. E_1 gives the shape of the wave of P.D. at the terminals of the condenser, and it is very similar to a sine curve. E_2 is the wave of P.D. at the terminals of the choking coil, and is triangular in shape. E is the wave of applied P.D. required to produce a parabolic current, and it will be seen that it is a peaky wave, very different from a sine curve. The diagram illustrates the general theorem that except when the applied P.D. wave is a sine curve, the wave of P.D. across the choking coil terminals is much more distorted from the sine shape than the wave of P.D. across the terminals of the condenser.

Resonance of Currents.—If we have (Fig. 5) a condenser

(K) shunted by a choking coil (L), then in certain cases the current in the main can be very small compared to either the choking coil or condenser current. Let c, i_1

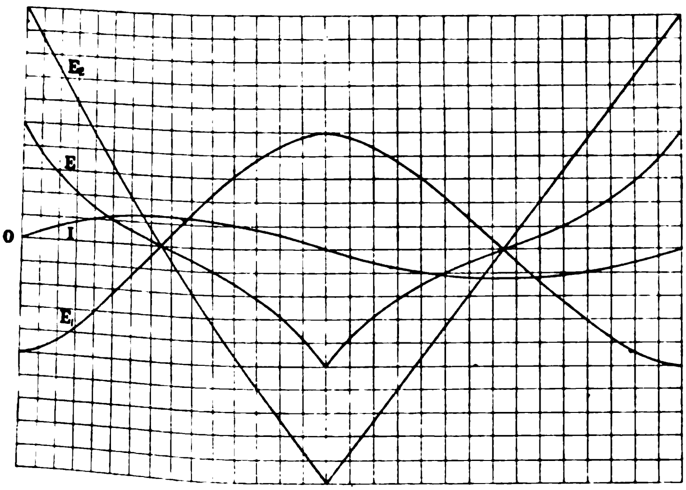
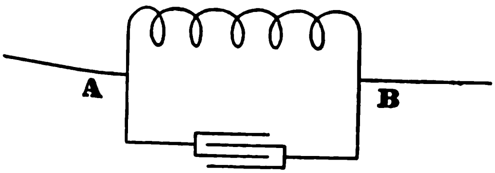


FIG. 4.

and i_2 be the instantaneous values of the P.D., the current in the condenser and the current in the choking coil, then—

$$i_1 = K\frac{de}{dt}\ ;\ e = L\frac{di_2}{dt}$$



Hence—

FIG. 5.

$$i_1 = K\,L\,\frac{d^2 i_2}{dt^2}$$

Now if C_1 and C_2 be the effective values of i_1 and i_2 we know that—

$$C_1 = \alpha\,V\,K f \text{ and } C_2 = \frac{V}{\beta\,L f}$$

where α and β are constants depending on the shape of the wave of P.D. Values of α and β for many curves are given

circuit is constant then this ratio equals R, and hence from (1), (2), and (3)

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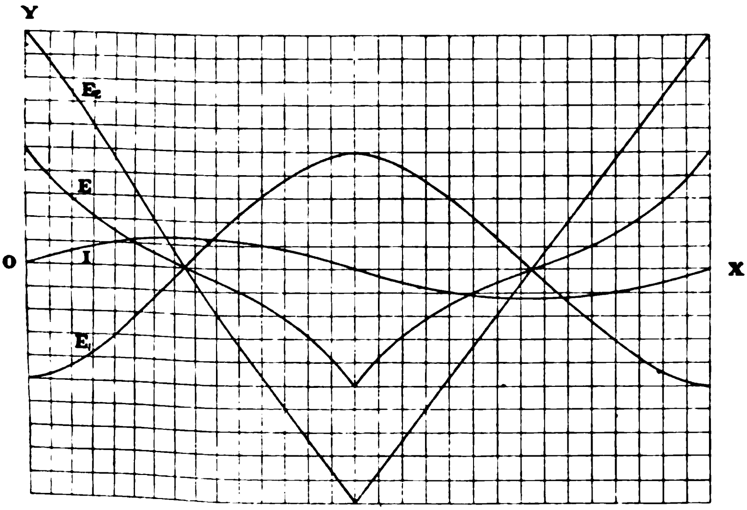

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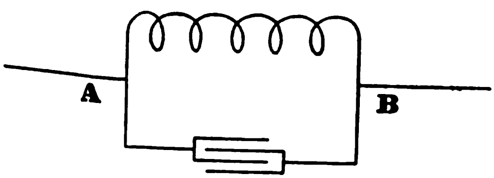

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$$C_1 = \alpha V K f \text{ and } C_2 = \frac{V}{\beta L f}$$

where α and β are constants depending on the shape of the wave of P.D. Values of α and β for many curves are given

in the *Journal*, vol. xxix., p. 154. If ϕ be the phase difference between the vector values of i_1 and i_2 then it is easy to show as before that—

$$\cos\phi = -\frac{K}{L}\,\frac{V^2}{C_1 C_2}$$
$$= -\frac{\beta}{a}$$

Hence ϕ only depends on the shape of the wave of the applied P.D. For very distorted waves ϕ is not much greater than 90 deg.

In Fig. 3, if O B represent the condenser current and O A the choking coil current, then O C will give the current in the main. If the capacity of the condenser is fixed, then the minimum value of the main current is $C_1 \sin\phi$, and if C_2 be the choking coil current, then in this case

$$C_2 = -C_1 \cos\phi$$
$$\therefore K L (\beta f)^2 = 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

If the inductance of the choking coil be fixed, then the minimum value of the current in the main is $C_2 \sin\phi$, and it has this value when,

$$K L (a f)^2 = 1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

Numerical Examples.

1. For a sine wave, ϕ is 180 deg. and the main current is zero when

$$K L (2\pi f)^2 = 1.$$

2. For a parabolic wave ϕ is 173° 46′, and if the condenser current is constant and equal to C_1 the minimum value of the current in the main is $0{\cdot}1086\, C_1$ and it has this value when

$$1{\cdot}001\; K L (2\pi f)^2 = 1.$$

Similarly if the current in the choking coil (C_2) be kept constant, the minimum value of the main current is $0{\cdot}1086\, C_2$, and it has this value when

$$1{\cdot}013\; K L (2\pi f)^2 = 1.$$

3. For a triangular wave ϕ is 155° 54′. When the condenser current varies the minimum value of the main current is $0{\cdot}4083\, C_1$, and in this case

$$1{\cdot}013\; K L (2\pi f)^2 = 1.$$

When the choking coil current varies, the minimum value of the main current is 0·4083 C_2, and we then have—

$$1·216\, K L (2 \pi f)^2 = 1.$$

Test for distortion of P.D. wave.—If a condenser shunted by a choking coil be adjusted so that—

$$K L (2 \pi f)^2 = 1$$

then

$$\frac{C_1}{C_2} = \frac{\alpha \beta}{4 \pi^2}$$

When C_1 is equal to C_2 the applied P.D. is sine-shaped, and the greater this ratio the more distorted from the sine shape will be the wave of P.D. Also if C be the current in the main, the smaller C is compared to either C_1 or C_2, the nearer is the shape of the applied wave to that of a sine curve.

Conclusions.—

(1) The power-factor of a resonant circuit can only be unity when the applied P.D. wave is sine-shaped.

(2) The rise of pressure in a resonant circuit depends on the shape of the current wave. If the ohmic resistance of the choking coil and leads is negligible, the maximum pressure across the condenser would be infinite for a sine wave, 9·22 times the applied pressure for a parabolic wave, and 2·45 times the applied pressure for a triangular wave.

(3) If we vary the inductance of the choking coil, then the pressure across the condenser terminals is a maximum when $K L (\beta f)^2$ equals unity, where β is a constant that depends on the shape of the current wave. The minimum value of β is 2π, and it has this value for a sine wave.

(4) If we shunt a choking coil with a variable condenser, then the minimum current in the main is got when $K L (\alpha f)^2$ equals unity, where α is a constant that depends on the shape of the P.D. wave.

When the P.D. wave is sine-shaped α equals 2π its minimum value.

(5) A condenser and a choking c
are connected by the relatio

$$L K (2 \pi f)^2 = 1$$

can be used as follows to
applied P.D. wave varies
Connect them in parallel and
main be C, in the condenser
coil C_2. Then the smaller th
C_1 or C_2 the more nearly doe
approach the sine shape. If
P.D. is sine-shaped, and the
to C_2 the more distorted the

(6) If the condenser and the chol
in series, and if $L K (2 \pi f)$
the voltage across the choki
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to V_1, the more distorted wil

JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. XXX. 1901. NO. 150.

The Three Hundred and Sixtieth Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 7th, 1901—Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on February 28th, 1901, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that they should be suspended.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Members :—

John Y. Nelson.

From the class of Associates to that of Associate-Members :—

Archibald John Walkom.

From the class of Students to that of Associates :—

George Henry van Corback.

Messrs. C. Stirling and W. Henderson were appointed scrutineers of the ballot for the election of new members.

INSULATION ON CABLES.

By MERVYN O'GORMAN, Member.

1. *Introductory.*—The value of cables made annually in England is, I estimate, £1,000,000 to £2,000,000, excluding submarine and telephone cables.[1] The gross profit might be £200,000, a good fraction of which goes to electricians, electro-chemists, managers, and little enough to purely scientific research. Yet such research might appear to be specially needed by the peculiarities of the industry, not only from the uniqueness of india-rubber, gutta-percha, lead, and copper, and from the large quantities used, but because in a cable factory, unlike other engineering works, the materials cost from ten to eighteen times as much as the labour of assembling them. A factory with 150 skilled and 150 unskilled hands can turn over £300,000 worth of goods in a year, *i.e.*, £2,000 per skilled man without complex machinery, and it is therefore essential, not only to buy with the utmost discretion, but to study the peculiarities of the materials and give importance to that branch of the "intelligence department" which deals with their electrical, chemical, and physical properties.

2. We scarcely realise how unlimited and how little explored are those fields of research. Suppose that by dint of mixing gums, resins, oils, powders, and solvents, we should get a perfect dielectric, *waterproof* for 100 years, *flexible and extensible*, so *volt-resisting* that the thinnest film suffices, with a specific *capacity* almost as low as that of air, yet adjustable to a high value; sufficiently firm not to decentralise, yet fluid enough when heated by an arc to close in and *seal-up* a fault. Suppose, besides all this, we can make it at 5d. per lb. applied, what will be the reward? Far more than the value of the 3-wire Patents or the Dunlop Tyre, plus the benediction of all electricians. Even if this insulator is not forthcoming, we may note that it is from studying electrolytes and dielectrics that we may solve not only some mechanical difficulties of armature design, capacity difficulties in submarine telephony, or the hygroscopic and electrolytic difficulties in wiring and tramway

[1] Last year's total cable-produce in the U.S.A. is reported to be fifteen million dollars (*Western Electrician* Century Number).

work, but also that we shall get in touch with discoveries such as the Nernst filament or modern investigations of the most burning interest such as the dielectric strains due to Hertz waves or Dr. Pupin's submarine telephony.

3. The subject is a large one from another point of view, for it is the value of the cables that practically decides us for alternating or direct currents, or that makes us prefer two or three phases, high or low voltages. It would be interesting to dissect critically the capital expenses of the electric supply industry (for power, or light or tramways or railways) and count the instances in which great expenditure has been made upon transforming plant of one kind or another, elaborate high-tension switchboards, extremely expensive insulation, to avoid an outlay on the copper of cables which time would have amply justified. Such a search would involve re-estimating most of the schemes, but it would show, I believe, that an important fact is lost sight of, the unparalleled endurance of copper. In the case of a large low-tension cable conveying, say, 1,000 kw. when the insulation has become valueless after an interval which may on the ordinary allowances for deterioration be fixed at thirty years, the value of the copper remains unaltered, say up to 70 per cent. of the value of the cable (supposed drawn into a duct). In the case of a high-tension cable such as 10,000 volts, however, should the insulation become worthless, the amount of copper in it is too small to be reclaimed, and at the end of thirty years' life a low-tension cable is worth 50 per cent. more than its rival. It is improbable that cable makers trouble about this, and in any case a high-tension cable, though a riskier thing to make than a low-tension one, is also more profitable, and is a better advertisement; so that even if they were consulted, which they are not, they would not discourage high-tension work. A cable maker, in so far as he re-sells copper which he has recently bought, is a merchant and obtains only a merchant's profits; in so far, however, as he converts by means of his patent and secret processes, paper, jute or rubber into an applied dielectric, he is a manufacturer, he takes certain risks and gives certain guarantees, but he obtains upon this material and labour the very much larger manufacturer's profits. Owing to the necessary subjection of the technical to the commercial side, we find the scientific manufacturer

becoming submerged in the merchant who knows his markets for the valuable G.P., rubber, lead, copper, and we find him biassed in favour of any good dielectric that will sell, and that will enable him to continue his profitable dealings in these goods, rather than turn his attention to the riskier channels of new dielectrics. He does not only object because the dielectrics are new; the merchant in him objects to the fact that he is not acquainted with the markets in which the new materials in question will have to be bought. As things are, he is right. He is assured of the permanency of the cable demand, and his fetish is a large turnover. Truly where there is a large turnover there will be good profits. In confirmation, we have seen in recent years (through the garb of more than one prospectus which reveals the form it seeks to hide) how a cable maker's "good-will" may fetch the sum of £10,000, £80,000, and £100,000. I think the public are well advised to buy, even where there is included in the good-will item a job stock of provisional rights and assorted patents of doubtful "fighting" value. The investor is justified by the permanency of the demand.

4. It is partly because the profits are great that the intelligence department does not strain forward. It is nothing to the commercial manager that all electric manifestations are essentially phenomena of the dielectric, or that in learning how to fill the intermolecular spaces of an oil with another oil, or a gum, or a powder, in linking constituents together or grading them to withstand disruptive stress, or in building up with design a substance of known dielectric constant, we cannot help tackling, and probably solving many problems of enormous scientific interest. This does not mean that manufacturers have not done, particularly at the inception of each new undertaking, some splendid work; but cables cannot be thrashed out like arc lamps, or coherers, and few are the cable makers who have read Oliver Heaviside or struggled with Maxwell.

5. The sources of expert information on the subject are very few outside the circle of manufacturers, each with his own ship to steer, and necessarily preoccupied if not biassed by that employment. Price lists still provide somewhat misleading schedules which show an increase of about 20 per cent. in price to correspond to a

large though almost useless gain in the measured megohms per mile, whereas whatever superiority there may be in a dearer quality of rubber, for example, is entirely dependent on the good faith of the maker, and is usually unverified by the purchaser, however scrupulously he exacts his extra megohms. Those who are ignorant on the subject must rely on the well-established makers' reputation to the detriment of new firms, however good their product and however much cheaper it may be. Within certain limits of price this is prudence, beyond these limits it is bad engineering, because there enters into the definition of "engineering" a word often omitted in academic books, the word "cheaply" —cheaply to apply the forces of Nature to the service of man. For example, when insulators other than rubber were first brought in, it was noticeable that new firms, whose guarantors were good, were sometimes passed by in spite of a difference of some thousand pounds in their favour; this difference, other things being equal,[1] is a measure of our deficiency of knowledge. Such things occur even now, and there still exists the rubber bigot and the paper bigot. Details of manufacture are not our only weak point, *e.g.*, it is only two years since the discovery was announced by Steinmetz[2] that the disruptive effect of a sinusoid alternating voltage on heavy oils is greater than that of peaky volt surgings from an induction coil, or high-frequency oscillations. Should not this have been known many years ago?

6. There is a work wanted in the electrical world on the lines of Professor Unwin's "Strength of Materials." When this exists we shall be more secure in throwing a stone at the "factor of safety" of civil engineers by calling it a mere "factor of ignorance" without fear of *tu quoque* in the matter of dielectrics, where we freely use factors of 20 or more.

7. It would appear that Edison's half-round conductors in a wrought-iron tube were amongst the earliest practical solutions of the distribution difficulty. He originally ran a bituminous mixture in between the parts, but later took to taping each conductor separately and then taping over both,

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before drawing the whole into the pipe. Lack of flexibility led to joints every 20 feet, and eventually these were made to bend by a ball-and-socket arrangement to allow for earth movements and expansion. The thick copper conducted heat away very fast, and soldering was extremely difficult.

8. Hopkinson's three-wire method displaced much of this two-wire cable, and later the American Section Underground Company made large cast-iron ducts intended for all kinds of cable on shelves, the shelves being expected to effect screening between telephone and other wires. The cost appears to have been very great, from the figure Mr. Kapp quotes (1886) of £3,000 a mile for a duct 10 inches by 15 inches. Proposals to revive this method for telephones in large towns are reappearing as an air-tight duct under dry-air pressure, and big enough for a man to pass through. The scheme is due to Messrs. Mortem and Kenney, and is perhaps not as visionary as it sounds.

9. *Brook's System* is little used. Heavy oils are drawn into the tube into which the jute-covered cable has been pulled. The tube is dried with dry air, the final drying being given by an excessive current in a special wire laid in the cable for the purpose.

10. *The Continental Underground Cable Company* trusted mainly to the insulation of an asphalt conduit kept dry by dry-air circulation, the cable being very lightly insulated as a safeguard. In 1886 Kapp had no further knowledge of this method or of where it had been tried, and this brings me to the centre of my subject.

11. *Lead-Covered Cables.*—Kapp, fifteen years ago, foresaw a future for them in low-tension work, but owing to the high capacity shown by Marcel-Duprez's 45 miles of experimental cable, Kapp concluded that "with the high pressure employed the lead covering of the cable acted as an enormous condenser and gave rise to heavy electrostatic induction. Lead-covered cables would only be applicable for currents of low E.M.F." He was not considering the all-compelling element of cost; dear rubber and cheap mineral products have turned the tables nowadays, and for 20,000 volts most engineers would consider rubber out of the question for any but short wires or perhaps for armoured cables.

12. *Cheapness.*—Even in the very early days cheapness

gained a hearing for fibre, when in 1795 bitumen cables and paper cables were foreshadowed by Francesco de Salva, who talked over 13 kilometers on a cable of 24 wires, each of which was covered by bitumenised paper and was made to attract a bit of paper bearing a letter of the alphabet.

The searchers after cheapness turned their attention naturally to the dielectric (which was six times the price of copper), and their quest led to four steps, partly bad and partly good :—

(1) The degrading of the rubber with chalk, etc. (sometimes to excess) and vulcanising it.
(2) The employment of metallic tubes, first rigid and later flexible, these being generally lead tubes containing cotton, jute, oiled paper, etc.
(3) The rigorous search for waterproof oils, gums, asphalt, celluloid, bitumen.
(4) Discarding flexible dielectrics in favour of bare copper supported in conduits.

13. *Degrading Rubber.*—The first step of the rubber-cable makers in compounding down their material was a step in the right direction, a step in the direction of experimental research which, in those days, was probably as valuable to the life of the electrical industry as the invention of the glow lamp. Nevertheless, that research was sometimes, and I believe *is* even at present often conducted in an unscientific way; otherwise the cable people who were the first in the field would never have let the industry slip so largely from them to the advantage of separate makers of the lead-covered and bitumen systems. There are many stories of how an individual foreman in the mixing shop used to discover by persistent minute modifications a recipe which succeeded and which he hid from his mates and his employer, revealing just enough to show that he had now become indispensable. An intelligent foreman himself told me that his payment was based on his producing cables at a reduced cost; he got half the reduction, whatever it was, on a certain schedule of prices: that foreman might mix how he liked so long as he passed the tests and the cables were sold. In three years he made such a good thing of it, that he, a

before drawing the whole into the pipe. Lack of flexibility led to joints every 20 feet, and eventually these were made to bend by a ball-and-socket arrangement to allow for earth movements and expansion. The thick copper conducted heat away very fast, and soldering was extremely difficult.

8. Hopkinson's three-wire method displaced much of this two-wire cable, and later the American Section Underground Company made large cast-iron ducts intended for all kinds of cable on shelves, the shelves being expected to effect screening between telephone and other wires. The cost appears to have been very great, from the figure Mr. Kapp quotes (1886) of £3,000 a mile for a duct 10 inches by 15 inches. Proposals to revive this method for telephones in large towns are reappearing as an air-tight duct under dry-air pressure, and big enough for a man to pass through. The scheme is due to Messrs. Mortem and Kenney, and is perhaps not as visionary as it sounds.

9. *Brook's System* is little used. Heavy oils are drawn into the tube into which the jute-covered cable has been pulled. The tube is dried with dry air, the final drying being given by an excessive current in a special wire laid in the cable for the purpose.

10. *The Continental Underground Cable Company* trusted mainly to the insulation of an asphalt conduit kept dry by dry-air circulation, the cable being very lightly insulated as a safeguard. In 1886 Kapp had no further knowledge of this method or of where it had been tried, and this brings me to the centre of my subject.

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workman, refused to compound and cancel his agreement for £600 a year, and he could not be got rid of.

14. This system of secret recipes may be unavoidable, but is, I think, a bad one for the industry, because instead of producing a school of scientific chemists learned in the art and selling their skill at a fair price, each progressing from where the other left off, the mixing foreman in any factory is prone to go independently over the old ground and make the same errors at the expense of, sometimes the purchaser and sometimes his employers. Several large companies employ expert analytical chemists versed in the matter of rubbers, but even these have too many heterogeneous duties to conduct a really productive research in an extremely difficult subject.

15. When too much loading is given to any rubber to hold, the rubber leaves go before very long, as is well known in the case of cheap garden-hose. If such an excess as this is not reached, there is still danger that the rubber may fail to entirely envelop the extraneous particles. The mixture then attains a quasi-hygroscopic quality which can only be detected electrically after a protracted immersion of a fortnight or a month. In this case the insulation resistance which is often very high initially, steadily falls while the specific capacity goes up. The test is easy to make in theory, but as cable is always wanted in a hurry and the maker is by no means disposed to cumber his tanks with a fortnight's produce (the tanks would have to be as big as his factory, and he says so in plain words) this test is hardly ever made.

16. *Hygroscopic Material in Metal Tubes.*—The value of this development, which we owe to the search for cheapness, need not be enlarged on. The relative prices of rubber and of such hygroscopic materials are somewhat as follows :—

	£ per ton.
Para rubber	400
Congo rubber (balls)	300
Celluloid	200
Castor oil	30
Amber grease M.P. 105° F....	26
Hard grease M.P. 114–116° F.	33
Refined special cotton oil	16·25

		£ per ton.
Oxidised cotton oil (nearly solid) ...	...	26
Thick resin oil	...	11·25
Ordinary resin oil	...	6
Rosin	...	6
Mineral oil	...	4·5
Pitch	from £40 to	2·25
Stearine pitch (flexible)	...	5·15

These hydrocarbons other than rubber are mostly supported on fibrous bases which themselves vary largely in price, and have different advantages dependent on their cellular construction. Thus:—

Good cotton (Egyptian) free from sheive	7d.	per lb.
Good linen yarn unbleached	7d.	„
Fine manilla paper	5d.	„
Good fine jute free from dirt and sheive...	3d.	„
Wood paper	$1\frac{3}{4}$d.	„

17. *Permanency.*—Of these, the best are unsized manilla paper and fine jute, because they possess some at least of the essential qualities of a cable dielectric, first among which is permanency. Whatever are the faults of permanent substances, we can know them and provide against them. Their capacity does not suddenly go up, or their insulation down. Permanency is always difficult to prove, and is always claimed for new compounds. I need hardly say it is rarely found.

18. Many of us have made dielectrics excellent in most respects, but which developed in the course of a year a crystalline structure which fell to powder on bending the cable. This is a common and more dangerous fault than is generally realised, and is often forgotten when a perfectly sound cable is withdrawn after a few years from one site and re-laid in another.

19. The methods which have survived till now are probably among the best, and I wish to point out what are the qualities, some faults, and some desirable improvements—(1) in the dielectrics, (2) in the conductors, (3) in the sheath, (4) in armouring and laying.[1]

[1] Owing to the length of this paper, the dielectric alone is dealt with here; the rest will be shortly published in book form.

20. *Dielectric.*—The object of the insulation is to insulate, but high megohms per mile of cable are important only in feeders to facilitate fault finding, and unimportant in distributor cables and house wires where there are many terminals. The number of probable terminals per mile of distributor or "points" per mile of house wire, settles the useful insulation by giving a measure of the weakest link in the chain. If the allowable leakage at any exposed points, say on porcelain blocks, were measured by 10 megohms, the leakage of the cable connecting these points might be measured by about 10 megohms also, and we are thereby led to tolerate in practice a cable test of, say, one megohm per mile for house wires and distributors. Such wires would be quite satisfactory when a consumer's premises are supplied by a separate transformer. Ten times this might be required when the supply comes from a low-tension network; but even there the insulation need not be so good when there are only small local networks supplied by small substations which are not interconnected.[1] The advantage of getting such a low test admitted verbally as well as tacitly, is that it throws open to research, and later perhaps to practical use, a large number of otherwise impossible substances, such as celluloid, low-grade acid-free pitch, clay, perhaps even some such chemical treatment as case-hardening on iron conductors, rust, oxide on aluminium conductors, etc. A further advantage of low insulation is that it diminishes the probability of high oscillating pressures when metallic switches are opened (as beautifully illustrated by Mr. Duddell recently), owing to the condenser being always shunted by a fairly low resistance.

21. Although there has been a feeling that the dielectrics of cables give lower tests under high pressures, there is some doubt as to the truth of this, and the variation is not marked.[2] It would seem that the lower tests are due to increased leakages at the ends, for experiments on dielectric liquids have shown that they obey Ohm's law, and that their specific resistance does not vary with the E.M.F. nor with the area of the opposed electrodes.[3]

[1] C. H. Wordingham points out this difference in M.E.A. 1896 Proceedings.
[2] Stuart Russell, "Cables," 1892 edition, p. 110.
[3] Naccari, *N. Cimento*, 8. 4. pp. 259–260, 1898.
The accident by which Ohm's law does not hold with gutta-percha, paraffin, and sulphur, probably gave rise to the original impression that no

A high E.M.F. would be useful in testing, however, by tending to decompose with sufficient rapidity for detection any water in the dielectric which might escape notice with lower voltage. Ohm's law, though not true for gutta, can probably be extended to plastic substances like bitumen, but no definite experimental data exist as far as I know for solids like paper and jute, with which there are great difficulties in experimenting, partly from the uncertainty as to the absence of water and the variations of chemical composition, and partly because it is not easy to say what the thickness of a piece of paper is.

22. In the case of feeders, especially for high-tension, the utility of being able to make a simple loop test to localise a high resistance fault without making allowances for the resultant of the normal leakage is good enough reason for using a high specific insulation. This property is, at least in the case of paper, rosin, rosin oil, and I believe also in the case of bitumen and rubber, not only not coincident with high specific disruptive strength, but is to some extent inversely as the strength. This, of course, is a reason in favour of allowing moderate megohms even on feeders.

23. As the price of cable depends upon its overall diameter to an extent not usually realised, every effort must be made to find substances of which very thin films give a high puncture resistance. If these could be got, we might be tempted to neglect the megohms on feeders as well as on distributors. As an example: the economy if the B.I.W. Co.'s Deptford main could have had a "radial" of 0·3 inches instead of 0·5 inches, and if the B.O.T. had waived the rule requiring $\frac{1}{10}$th inch per 2,000 volts, would have been some hundreds of pounds.[1] On the other hand, the megohms would have been less, not in proportion, but according perhaps to an inverse log law, except in the unlikely event of the new substance possessing both insulation and disruptive strength in a proportionate degree.

24. A temptation to the early workers to seek a very high test in megohms for cables exposed to hitherto unused pressures, may have arisen from the consideration that if the

insulator obeys it. For example, thin gutta shows less insulation resistance (specific) than thick, and is also less insulating when measured with higher current densities.

[1] As a matter of fact they did gain some hundred pounds' worth of lead and insulation by the use of sector-shaped copper on the outer conductors. This will be separately considered under "Conductors," loss in stranding, etc.

insulation were absolute there would be no current through the dielectric, and the erroneous deduction that there would therefore be no fear of any electric disintegration with lapse of time.[1] Experience proves that sufficient security is obtained with comparatively few megohms, and large cables, say 19/16, such as I have myself made and tested, having 50,000 megohms per mile, are now unheard of.

25. *Electrolytes at High Voltages.*—Moreover, if we accept the Electrolytic theory of dissociation, we find that absolute insulation will not protect us against decomposition by electrostatic attraction of the ions if an electrolyte is on either side of the supposed absolute insulator. Nernst[2] and Ostwald have made the experiment under the microscope, and it is well to be on the safe side and adopt their conclusion that it also occurs in a degree at all practical voltages, however small. Further, as cations and anions travel at different velocities, we have no certainty, where any electrolyte is present within the pores of a perfect insulator, that even an alternating current at ordinary frequencies is a full security against decomposition.[3] If this consideration is of any importance we must avoid electrolytes, that is, acids, bases and salts, and confine our dielectrics to chemically inactive organic compounds, or non-electrolytes, whose class distinction is :—

(i) Non-conductivity.

(ii) That they exert a normal osmotic pressure (that is, in accordance with the law $PV/T = i\ R$.

26. I think that rubber makers sin in this particular way by using electrolyte salts in their compounding. Mr. Alexander Siemens, himself a large maker of rubber cables, made the following pronouncement before the M.E.A. in 1896 : "His firm had long ago come to the conclusion that rubber cables, unless lead-covered, were no good. They were absolutely certain to lose their insulation, especially in places where they were alternately wet and dry." Mr. O.

[1] S. A. Russell, "Cables," 1892 edition, p. 114 raises this question, which can now be answered in the negative as in the text.

[2] *Zeitschr. Phys. Chem.* 3, p. 271, 1888.

[3] This consideration is not altered by Carmichael and Swyngedauw's experiments, which, in so far as their results were negative, only show that a circuit, if composed entirely of electrolytes, is not decomposed. Thus they made a transformer with an electrolyte secondary ; they also formed a closed circuit of electrolytes, the contacts between which gave rise to an E.M.F., and observed no decomposition (*Comptes Rendus*, 131, p. 375, Aug., 1900).

Schaeffer, of the Duisburg Cable Co., also prefers not to guarantee any rubber not lead-covered.

27. This absence of acids, etc., has never yet been entirely secured, as far as I know. On the other hand, Professor Kennedy gave evidence in 1898, before the Joint Committee on "Electric Energy," to the effect that modern mains might be relied on for thirty years; and as large numbers of modern mains contain electrolytes, this is testimony to the slowness of the action in question, at all events at modern relatively low voltages.

28. The amount of the presumable increase of what might be called electrostatic depreciation, including the formation of ozone, etc., at very high pressures, is, as far as I am aware, unknown up to the present, and must be risked, unless some of the great power companies choose to pay for having this and many other important matters scientifically investigated before buying their cables, for there is no doubt that the present fashion of shirking voltages above 10,000 max. must pass away if we are to make serious progress in long-distance work in England (*cp.* footnote 1, par. 48).

29. *Volt-Resistance.*—Such a research would incidentally explain a surprising fact about our high-tension cables, namely, the large thickness of dielectric required, compared to the actual strength of the materials employed.[1] A single strip

[1] T. Gray made an interesting series of measurements on dielectric strengths, and his results given below may be taken as roughly comparable, though they are open to the objections that he used large spherical surfaces, took his voltages on the primary of a step-up transformer and assumed that a thick dielectric was reproduced by superposing a number of sheets :—

	Max. strength on Kilovolts per cm.
Glass ...	285
Hard rubber ...	538
Soft rubber ...	476
Soft rubber (2nd quality)	492
Mica ...	2,000
Micanite ...	4,000
Papers paraffined—	
Manilla wrapping ...	430
American linen ...	540
Blotting felt...	150
Fuller braid ...	295
Empire cloth ...	310
Empire paper ...	450
Lubricating oil ...	48
Linseed oil ...	83
Cotton-seed oil ...	67
Air 0·02 cm. between plates ...	57
Air 1·6 cm. between plates ...	27

(T. Gray, *Phys. Rev.* 7, pp. 199–209, 1898). If we could only secure this strength in practice, what an enormous gain would be made.

of pure dry manilla paper, weighing 70 grammes per square metre and about 0·004 inches thick, will resist 1,000 volts max. (for weeks, and I think indefinitely) when tightly wrapped on a length of small wire and tightly lead-covered: four such papers impregnated with rosin and rosin oil will sometimes resist as much as 12,000 volts alternating on a length of cable; and yet twenty such papers, making a thickness as 0·08 inch (an ordinary low-tension radial depth), cannot by any means be expected to withstand 50,000 volts on long lengths, though on a yard length of 7/16, say, they frequently will. A suggested reason for the superior strength of the short piece is that in a 100-yard length the probability of a streak of dirt or moisture, or of metallic particles, or of the oil having been crushed out of the paper in bending the cable, or of a bubble or vacuous space, or of an irregularity in the dielectric capacity, is one hundred times greater than in the one-yard length. Indeed, except to verify the mechanical effect of severe bending, any high-pressure test on a *short* length of cable proves nothing whatever about the bulk.

30. Similarly a test for disruptive strength on small thicknesses proves nothing about a large thickness of the same material, because a diminishing dielectric strength with increasing thickness is apparently inherent in most insulators, unless we allow that the experimenters whose results are available have made errors of remarkable similarity (see Appendix, T. Gray's tests on four oils).

31. I think Professor Perry would ascribe part of the apparent extra strength of small thicknesses to the preponderance of skin-resistance when the total resistance is small. The weakness of the larger thicknesses might also be partly ascribed to the fact that when the electrodes are no longer very large compared to the spark-gap, the stress lines will no longer be uniform, and the potential gradient will at some part of the insulation be greater than is given by the total voltage divided by the total distance between electrodes. There is also the extra likelihood of impurities.

32. *Bubbles.*—Not only must the mechanical formation of the smallest bubble be avoided in cable manufacture, but their electrical production must be guarded against. The insulation of a cable between concentric conductors or under the lead differs greatly from the slabs of the substance

to which inventors are always so happy to apply high voltages by means of a couple of brass balls or plates. The brass-ball test is worthless.

33. *The* way to test a dielectric is on a length of cable. The area of surface of insulator under strain in a length of cable is enormously greater than in the case of a slab; the contact between metal and dielectric is more thorough, the curve of stress is totally different, the cable material will necessarily have to be bent about and handled, and, most important, the average value of the insulator, bubbles and all, is tried, instead of a single selected square decimeter. Bubbles are a great enemy of permanency and tend to loss of energy. If we refer to Berthelot's experiments[1] (*Science Abstracts*, 1050, vol. ii.) on layers of dielectrics subjected to a high alternating E.M.F., we shall see that large numbers of substances are either polymerised under the treatment, or give off bubbles of hydrogen or water.[2]

34. The reason for objecting to bubbles is not usually appreciated: not only does the possibility of a single bubble increase the thickness of the dielectric throughout and thus add to the cost of the cable, but even the increased thickness is not as effective as the thinner dielectric if the insulator were continuous. This inefficiency of the thicker material (unless the increased thickness is equal to the diameter of the bubble) is shown by an experiment which is perhaps not as well known as it deserves to be :—

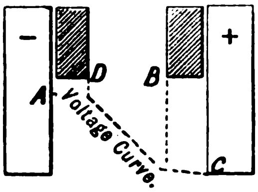

FIG. 1.

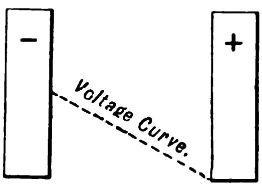

FIG. 2.

[1] *Annal. Chim. Phys.* 16, pp. 5–80, 1899.

[2] Thus olive oil is polymerised in twenty-four hours; alcohol gives off hydrogen and ethane; the ethelene series is polymerised, loses hydrogen and approaches the camphene series; formenes are converted into ethylenes. The fatty alcohols will absorb nitrogen if present from amidines and give off hydrogen. Some of the particular substances here mentioned are interesting because their reactions tend to preclude the use of that most promising modern material, celluloid, in the solution and treatment of which they are used. Berthelot used induction-coil currents, which, as before stated, are less severe than sinusoid currents in puncturing if not in chemical effect. However, high-frequency currents probably occur on every system direct and alternating.

35. If we arrange two conductors A, C, at such a distance apart that the air is just able to withstand for an indefinite time, say, 10,000 volts maintained by a transformer, and then introduce between them a strip or two of glass or ebonite D, B, the insulation breaks down, although the glass is a more volt-resisting substance than an equal thickness of air. This experiment was shown by Tesla, and taken by him to show that ebonite was a less resisting substance than commonly supposed. The explanation, however, is very different and quite simple: the rate of fall of volts per centimetre of air is the highest the air can withstand; as glass has a higher specific capacity the potential gradient in the glass is less steep than in the air, and the consequent increased steepness in D B punctures the air; and the heated glass thereupon soon gets hot and gives way under the alternating potentials.[1]

36. *Uniformity of Texture.*—This experiment leads up to the idea of uniformity of texture in all classes of insulating materials which are built up in successive thin layers, especially when the layers as in paper cables may not be closely compacted together for fear of losing flexibility, or when the layers as in rubber cables have (to economise the more expensive insulators or to separate the copper from sulphur) to be composed of dissimilar compounds. With our present methods of manufacture it would seem that security is got in the one case by seeing that the impregnating oil has approximately the same specific capacity as the paper fibre, and avoiding crumpled paper, not a difficult matter; and in the other by avoiding too great a difference between the compositions of the coats.

37. It is usual to make rubber cables with the better grade material next to the pure rubber (this can be tested any day by stretching the insulation of a cable till it breaks, the outer coat always gives way first), because a higher test is got in this way with less of the high-grade material; but unless the specific capacity of the high and low grade is properly adjusted or made to be the same, which it usually is *not*, the disruptive strength of the finished cable will suffer under alternating pressures.

38. "*Grading.*"—I suggest this name for a method of adjusting the specific capacity, dielectric strength and con-

[1] R. E. Fessenden (Amer. Inst. El. Eng., 1898), gives this experiment.

ductivity of the covering of a cable so that the materials composing it occupy the best possible positions, whether for resisting puncture or diminishing the energy loss in the insulation.

This is to be done by departing from the strict homogeneity above recommended for cables as hitherto manufactured.

Let us consider what happens in a cable dielectric where there is a difference between the potential of the core and that of the lead sheath. The insulator and conductor may

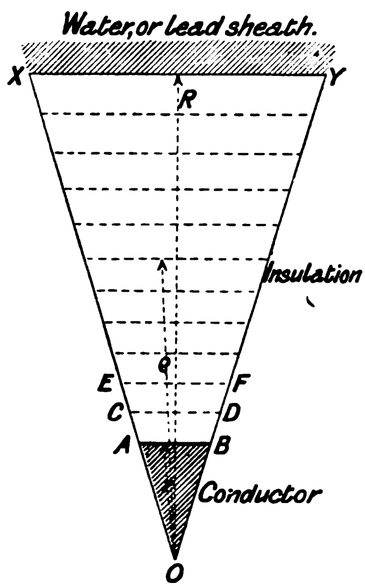

FIG. 3.

be supposed made up of layers of equal thickness as in a paper-covered cable, and these may be developed as in Fig. 3, in which the vertical scale has been purposely exaggerated to show the thickness of the layers.

Let the length of the horizontal line A B equal the circumference of the conductor of radius r.

Let the length of the horizontal line X Y equal the circumference of the insulation of radius R.

Let the perpendicular distance between lines A B and X Y equal the thickness of the insulation.

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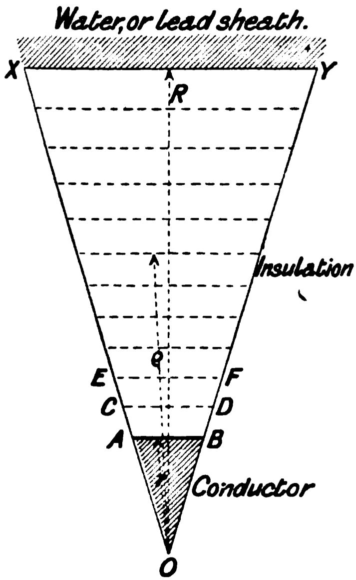

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Let the length of the horizontal line X Y equal the circumference of the insulation of radius R.

Let the perpendicular distance between lines A B and X Y equal the thickness of the insulation.

Let the perpendicular distance between the line A B and O equal the radius of the copper.

Then if the conductor is raised to 14,140 volts and X Y remains at zero volts, there will be a current through the dielectric from A B to X Y, and the fall of volts from A B to X Y, which is 14,140, will in each layer be proportional to the resistance of that layer in ohms.[1] That is, it will be proportional to the length of the lines A B, C D, etc., to X Y, which are inversely as ρ, where ρ is the distance of any layer from O.

Drawing the curve of potential in the dielectric from this law [2] for a 37/14 with half an inch of insulation, we get Fig. 4 curve 1. The steepness of this curve or its gradient at any distance from the core is measured by the angle the tangent makes with the horizontal, and in Fig. 4 curve 2 the length of each ordinate represents this steepness.

39. When the fall of volts across an element of thickness is great, the disruptive stress is proportionally great,[3] and therefore Fig. 4 curve 2 shows what stress a uniform dielectric, on a cable under continuous pressure, is subjected to throughout its thickness (*i.e.* between r and R of Fig. 3). This stress is greater near the conductor, and diminishes from the conductor outwards.

40. If we wish to increase the working pressure without exceeding this stress, which (if the cable is properly designed) should be no more and no less than the maximum safely allowed by the specific strength of commercial insulation as used, it is at present usual to add more layers of insulation outside layer X Y. This, however, is exceedingly expensive (see Fig. 13), because from the nature of the curve of gradients the depth and cost of insulation increases very much more rapidly than the voltage. Thus, in the example used for the curves of Fig. 4—

A 37/14 at 10,000 R.M.S. volts takes ½ inch of insulation; [4]

A 37/14 at 20,000 R.M.S. volts takes 1·89 inches of insulation;

[1] I have suggested on page 617 how far Ohm's law may be justly applied to insulators (see Naccari, *N. Cimento*, 8.4. pp. 259–260).

[2] The equation to this curve is No. 6 on page 637, where V_0 = 14,140 volts.

[3] Not only does Maxwell appear to be satisfied as to this proportionality, but I think experimental evidence (Lombardi, T. Gray, and others) confirms it within the thickness of a continuous dielectric under strain.

[4] Chosen because this is the size and voltage of the Deptford main.

37/14 Cable at 10,000 R.M.S. Volts.

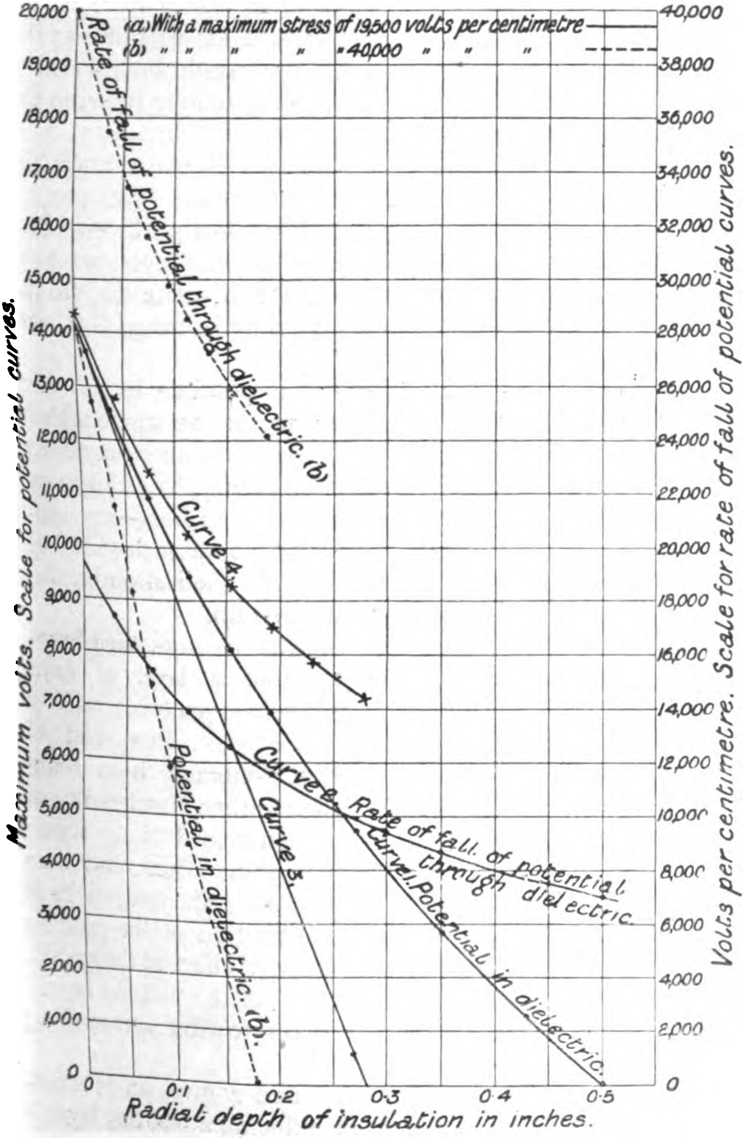

FIG. 4.

Let the perpendicular distance between the line A B and O equal the radius of the copper.

Then if the conductor is raised to 14,140 volts and X Y remains at zero volts, there will be a current through the dielectric from A B to X Y, and the fall of volts from A B to X Y, which is 14,140, will in each layer be proportional to the resistance of that layer in ohms.[1] That is, it will be proportional to the length of the lines A B, C D, etc., to X Y, which are inversely as ρ, where ρ is the distance of any layer from O.

Drawing the curve of potential in the dielectric from this law[2] for a 37/14 with half an inch of insulation, we get Fig. 4 curve 1. The steepness of this curve or its gradient at any distance from the core is measured by the angle the tangent makes with the horizontal, and in Fig. 4 curve 2 the length of each ordinate represents this steepness.

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A 37/14 at 10,000 R.M.S. volts takes $\frac{1}{2}$ inch of insulation;[4]

A 37/14 at 20,000 R.M.S. volts takes 1·89 inches of insulation;

[1] I have suggested on page 617 how far Ohm's law may be justly applied to insulators (see Naccari, *N. Cimento*, 8.4. pp. 259–260).

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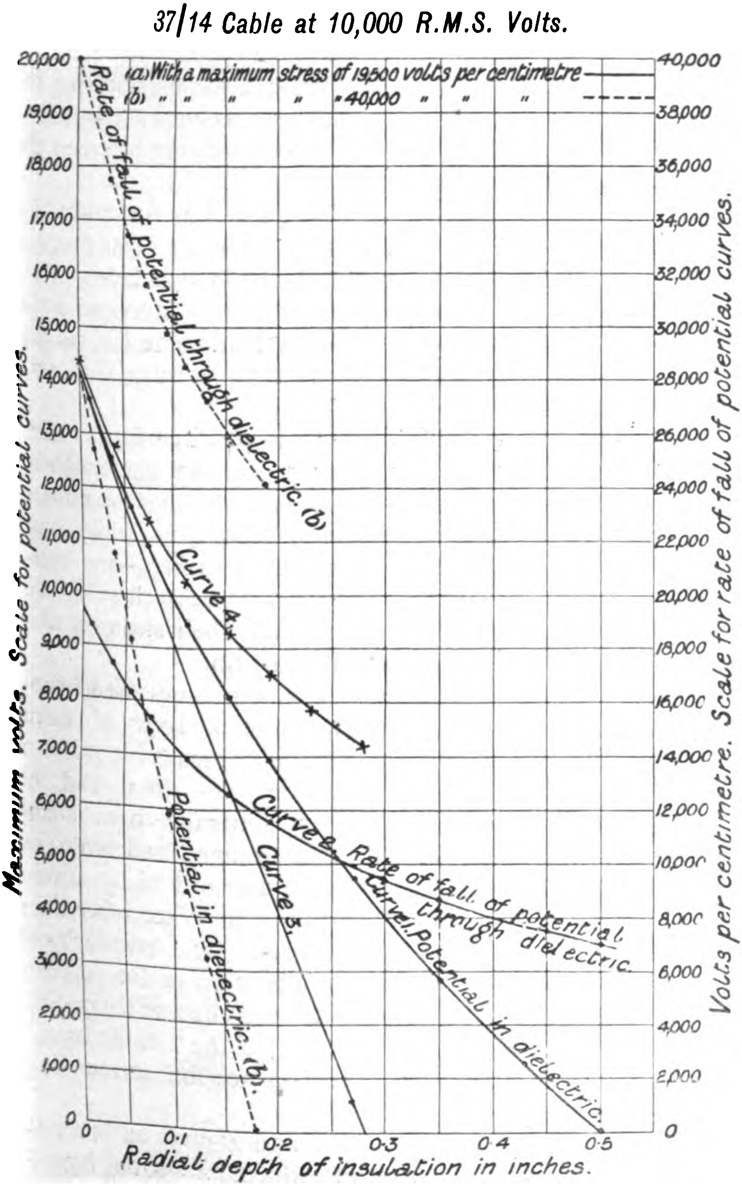
37/14 Cable at 10,000 R.M.S. Volts.
(a) With a maximum stress of 19,500 volts per centimetre
(b) " " " " 40,000 " " "
Rate of fall of potential through dielectric. (b)
Curve A.
Curve B.
Curve C.
Curve D. Rate of fall of potential through dielectric.
Curve E. Potential in dielectric.
Potential in dielectric. (b).
Maximum volts. Scale for potential curves.
Volts per centimetre. Scale for rate of fall of potential curves.
Radial depth of insulation in inches.
20,000
19,000
18,000
17,000
16,000
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
40,000
38,000
36,000
34,000
32,000
30,000
28,000
26,000
24,000
22,000
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
0
0·1
0·2
0·3
0·4
0·5

FIG. 4.

A 37/14 at 30,000 R.M.S. volts takes 5·3 inches of insulation;

whereas there are three ways none of which have, as far as I am aware, been suggested before for negotiating the steepest gradient while making no increase in the insulation thickness beyond that of direct proportionality between the thickness and voltage used.

41. The first method is obvious: it is to make the dielectric strength of the insulation in each layer proportional to the stress (or voltage gradient) in that layer. This may be done by multiplying the number of layers so as to utilise skin resistance or by using special materials, for the inner or highly stressed layers, for example, mica, G.P., etc., which has a high strength.

42. Only a small improvement is possible in this way, because many makers already employ for the whole of their insulation the strongest material that combines the various qualities of economy, flexibility, permanency, etc., while many others—for example, the rubber cable makers—are compelled by other considerations to put some such substance as pure rubber, which is not, I think, their strongest dielectric, into the position of greatest strain.

43. It is true that makers have sometimes tried introducing in the covering of a cable a layer of extra strong and proportionately expensive material, with a view to diminishing the diameter and total cost of insulation, but the attempt has generally been abandoned because the results were either inadequate or irregular. The inadequacy may be ascribed to the strong dielectric layer being usually put in some place other than where the potential gradient is steepest. The irregularity of the results is probably due to the alteration of the position of the steepest gradient by the unnoticed effect of the specific conductivity or the specific capacity of the "strong layer" displacing the strain from itself on to the surrounding weaker dielectric.

44. The experiment of Figs. 1 and 2 gives an interesting example of the danger of introducing a "strong layer" without having regard to the effect of capacity on the gradient.

The second and third methods of diminishing the thick-

ness of insulation consist in utilising these apparently objectionable qualities of conductivity and specific inductive capacity, and adjusting or grading them in each layer of the covering of the cable.

45. *The Conductivity Method.*—By referring to Fig. 3 if we make the specific conductivity of the inner layers of the insulation greater than the average, the difference of voltage between the two sides of each of these layers will thereby be reduced. In fact we may so adjust the specific conductivity of all the layers that the fall of potential in each of them is uniform. If 20,000 volts to the centimetre may be assumed to be the maximum safe gradient in the particular material under consideration, the curve of voltage (which now becomes a straight line) is shown in Fig. 4 curve 3, the stress is uniform throughout, and is a straight horizontal line, no portion of the dielectric is more idle than another, and the total thickness of dielectric required is 0·275″, instead of 0·5″. We shall now find that a

37/14 at 14,140 volts (continuous) only requires — 0·275″
do. do. 28,280 „ „ „ „ — 0·550″
do. do. 42,420 „ „ „ „ — 0·825″

The means for obtaining this result is simple. The exact specific conductivity to be given to each layer bears a direct proportion to the ordinate of the curve of gradient plotted as shown in curve 4, Fig. 4.

46. This curve is in every respect similar to curve 2, Fig. 5, save that the radial depth of dielectric for which it is calculated is reduced from 0·5″ to 0·275″.

47. If the insulation of the cable is paper and rosin oil, the conductivity of the inner layers is easily lowered 50 or 100 per cent., as required by the curve of gradients, by adding to the impregnating fluid used on the layers a very small percentage of linseed oil, which has no appreciable effect on the disruptive strength and is too small in quantity to effect any practical alteration in the specific capacity of the layers "graded" by its use thus—

No. of Layer.		Thickness.		Per Cent. of Linseed Oil added.
1st outside	...	0·08″	...	0
2nd next	...	0·05″	...	0·0012
3rd „	...	0·05″	...	0·0023
4th „	...	0·05″	...	0·0042
5th inside	...	0·05″	...	0·0065

This method loses value (1) because of the large effect of small impurities; (2) because of the temperature co-efficients of the oils.

48. *Capacity Method.*—The specific capacity K of any one quality of insulation can be obtained from a cable covered with it by using the well-known formula—

$$K = \frac{M \log_{10} \frac{R}{r}}{\cdot 000439} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where M is the capacity of an immersed (or lead-covered) cable per mile in microfarads, and R and r are respectively the outside radii of the insulation and conductor. Mr. Mordey made experiments on a particular rubber cable for which M was the same when obtained at any alternating voltage V from the formula $M = \frac{10^6 A}{2 \pi n V}$, and this result coincided with the direct-current ballistic measurement. It is probable that the formula is approximate enough with sine curves alternators of any frequency n ("A" being the alternate R.M.S. current in amperes).[1] For accurate measurements it must be remembered that the results depend (1) essentially on the *sine* curve and (2) if the frequency is varied on the particular dielectric; Arno has found as much as 3 per cent. difference, and Lombardi,[2] H. V. Carpenter, and others have independently come to similar conclusions.

49. When the capacity is required of a powder, or a gum in the rough or an oil, or of a substance having a difficult

[1] An extension of Mr. Mordey's test [I.E.E. Journal, January 10, 1901] was made on three miles of 25,000-volt cable at the St. Croix Co., Wisconsin, U.S.A., on October 14, 1900, after laying and jointing. The frequency was kept constant and the charging current and voltage-curve was a straight line through the origin, thus showing that the capacity was constant at all voltages. Mr. Mordey's test was on rubber; this was on paper cable.

[2] L. Lombardi (*Appendice all' Annario*, 1898–1899, *Museo Industriale Torino*, pp. 77) tested 60 metres of Cortalloid cable (r = 0·25; R = 0·55) impregnated with tar, and lead-covered, and found the capacity to be 0·032 mfd. with direct currents, and 0·028 mfd. with alternating—a very large variation. Lombardi (*L'Elettricista*, 5, pp. 1–8, 25–32, 1896; *Beiblatter*, vol. xx. p. 546) also made capacity measurements on condensers of different types and with different dielectrics by means of alternating currents the E.M.F. curve of which was exactly determined, and showed that with medium frequencies the apparent value of the capacity was different from and smaller than that with continuous pressures and considerable times of charging. The capacity is somewhat dependent on the frequency, but its variation, with good condensers, can, for practical purposes, be made inappreciable.

shape to deal with like paper, jute, cotton, or hemp, the specific capacity may be obtained according to a method, which I think is due to Nernst. The specific capacity of a volume of oil (which does not re-act on the powder, etc.) is measured, the powder is added and the mixture measured again. If the capacity of the mixture is not altered by the added substance, its specific capacity is found. If not, another known oil is used and the process repeated. In the case of roasted manilla paper the method gave the approximate result of 1·8 (air=1)[1] for one sample of paper and 2·6 for another.

50. Among innumerable methods of finding specific capacities may be mentioned that of C. B. Thwing, who obtains it from the chemical composition, density, and molecular weight of a substance and its components.[2] Briefly he showed that the specific capacity

$$K = D/M\ (a_1 k_1 + a_2 k_2 + a_3 k_3 + \text{etc.}) \quad . \quad . \quad (3)$$

where D = the density and M the molecular weight of the substance, and $a_1\ a_2\ a_3\ k_1\ k_2\ k_3$ the number of atoms or atom groups and their dielectric constants respectively.

Substance.	Formula.	D.	M.	K. calculated.	K. measured.
Water ...	H O H	1	18	75·5	75·5 78·5
Glycerine ...	$C_3H_5(OH)_3$	1·26	92	57·17	56·2
Petroleum ...	...	0·8	...	2·08	2·06
Paraffin ...	...	0·87	...	2·26	2·28 1·99 2·32 etc.
Turpentine	$C_{10}H_{16}$	0·87	...	2·23	2·23
Chalk	CaO CO_2	2·65	...	6·89	6·14

51. In compiling the table in the Appendix, I had thought of referring to Maxwell's law that "specific inductive capacity

[1] A. Gray. "Absolute Measurements" gives the precautions to be taken in experimenting on capacity. The dearth of results giving s.i.c. at known temperatures of substances having a known chemical constitution is astonishing.

[2] *Zeitschrift für Physik & Chimie*, p. 297, vol. ii.

multiplied by permeability equals the square of the index of refraction," but it is unfortunately of no use. It only holds for very long waves, and is apparently subject to great discrepancies.

52. The utilisation of specific capacity deserves to be considered because its economic importance has not yet been fully realised by cable makers, many of whom have perhaps overlooked the fact exemplified by the experiment of Fig. 1 and 2 that across a composite insulation the potential gradient divides itself inversely as the specific capacity of the various separate layers.

53. Substances of dissimilar specific capacities can be utilised in much the same way as those of dissimilar conductivities for grading the layers of insulation and obtaining a uniform stress in all parts of the coating of a cable under alternating pressures. Even with continuous currents the specific capacity of the various layers of the insulation is of importance, *e.g.*, when the cable is first switched on because the maximum stresses are frequently of a rapidly alternating character.

54. Consider a homogeneous insulation to be made up of elementary condensers in series (Fig. 5), and disregard the conductivity of the dielectric for the moment.

55. As all the condensers receive the same charge and are of the same material and thickness, the potential difference between the plates of each elementary condenser is less as its area is greater. That is, the gradient, or fall of volts across the element of thickness is inversely as the area—that is, inversely as the radial distance ρ of any elementary condenser from the centre. This gives us, again, the curve of potential Fig. 4, curve 1 on the 37/14 cable.

56. If now we arrange the specific capacity of every layer of the insulation so that the elementary condensers have, in spite of the difference of area, the same capacity, then when they are all given the same charge, they will have the same difference of pressure between their two sides—that is, the stress in every part of the dielectric will be uniform. This method has, I think, a serious practical utility, and the "grading" should be calculated, not for the working maximum volts, but for the probable greatest maximum volts.

57. A brief search among the available insulators shows that it is apparently easier, without detriment to disruptive strength, to adjust conductivities than capacities by an admixture of small quantities of a less insulating substance, but even for direct currents there is a theoretical advantage to be gained by choosing that substance with a higher specific capacity than the matrix or insulation proper. Substances of any specific capacity immersed in a di-

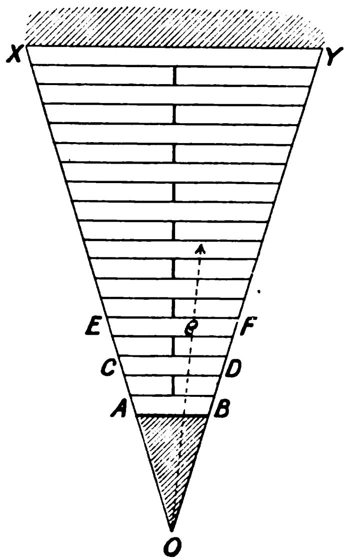

FIG. 5.

electric of a lower capacity tend to move slowly towards the place of steepest potential gradient. If there should remain after careful "grading" a slightly steeper potential slope near the inner conductor, for example, of a concentric cable, a tendency is thereby established which will oppose diffusion, and will tend to maintain or improve the prearranged disposition if the order of both conductivities and capacities is properly chosen.[1]

[1] Some such words as the following are to be found in Heaviside's Electro-Magnetic Theory, vol. 1, art. 81.

"A sphere of uniform permittivity in a uniform electric field causes the external lines of electric force to be symmetrically distorted fore and aft, and therefore it has no tendency to move."

If, however, the body be a very small piece in a field which is not uniform, it tends to move in the direction in which the energy or stress in the field increases most rapidly, independent of the direction of the electric force

58. When the outside of an insulated conductor is not exactly circular, but is either a number of small part circles, as in a strand of round wires, or sector-shaped and therefore offering two or more approximately flat surfaces and corners, which are usually rounded off, the electric intensity [1] will be greatest in the insulation which is nearest to the most protruding portion of the smaller curvatures of the conductor, and the potential gradients will be proportionately steep and will tend to disrupt the insulation unless correction is made by either increasing the thickness of total insulation, as is done at present, or increasing the dielectric strength locally, or increasing the specific inductive capacity so as everywhere to correspond with the steepness of the potential gradient.

59. The curve of gradients for any usual arrangement of conductors may be graphically obtained with sufficient approximation for practical purposes, and for this we shall utilise the apparently unimportant similarity between the curve of potential obtained by considering first conductivity, and secondly capacity.

The following suggestion which Professor Perry kindly made to me is of special assistance in the somewhat difficult case of a 3-phase or 2-phase cable. An enlarged section model of the cable is made and the conductors and sheath (if any) are maintained by accumulators at potentials proportionate to the instantaneous value of their potentials when in use; say 4 volts, 2 volts, and zero volts for a 3-phase cable. A thin sheet of high resistance metal is laid across the section, and the equipotential lines are then plotted by pricking holes with two needles connected to a galvanometer, at those places where no deflection is obtained.[2] Such an arrangement clearly takes no account of capacity. But an alternating potential at commercial frequencies may be said to take no account of conductivity, and so we thus get the curve which we require. We can then confirm it mathematically by following out *Mie's* work on Poynting's Theorem.[3]

when the permittivity of the body exceeds that of the medium. It will move in the opposite direction when the permittivity is less than that of the medium.

[1] This is a measure of the gradient and therefore of the stress; see short quotation from Maxwell in a footnote to p. 678.

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[3] See a paper on Poynting's Theorem by G. Mie, in *Zeitschr. Phys. Chem.* 34. pp. 523, Sept. 7, 1900, briefly abstracted, translated and followed out for practical use in Appendix vii.

60. When the dielectric matrix can be made sufficiently fluid by heat, and is free from interposed solids, the grading might conceivably be effected by maintaining a difference of potential between the conductors. To prevent the substances from reverting, when the potential difference is cut off, to any other undesired arrangement of capacities, they might be so chosen that they should solidify or become highly viscous with time or by cooling, etc. Such a method would not only be slow, but might be imperfect owing to the forces being small.

Example of 37/14 "graded" cable to stand 14,140 volts maximum:—

No. of Layer.	Thickness.	Spec. Capacity.	Per Cent. of Castor Oil.
1st outside	·08″	2	0
2nd next	·05	2·27	9·5
3rd „	·05	2·57	20·5
4th „	·05	2·93	33·0
5th inside	·05	3·40	50·0

61. As now made cables are often inversely "graded." A large class of fibre cables are given their final impregnation by immersing them in their entirety in a tank full of a mixture of an oil and some solid hydro-carbon, which, as in the case of rosin, frequently has a higher specific capacity than the oil and paper, as well as a greater disruptive strength.

62. During the process of this impregnation the fibres of the outer layers have the effect of filtering the solute from the solvent, and although the oil reaches and fills up all the pores of the innermost layers of paper, the solid is filtered away and only reaches the outer portion of the dielectric, which consequently has the greater dielectric strength and capacity, where they are not wanted.

63. That the dielectric strength should be greater in this particular position is of little consequence, but that the capacity should be greater is a danger, because it tends to make the potential gradient steeper even than it would be in a homogeneous insulation close to the conductor. On the other hand, it would be worth trying to utilise this fact to graduate the conductivity or capacity by choosing the oil and solid to have a suitable viscosity at the temperature of the impregnating tank.

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64. A similar faulty arrangement is met with in ordinary

vulcanised rubber cables. The pure rubber which is placed next the conductor has a specific capacity of about 2·3. The high-class compound which comes next to this may have a capacity of 2·6, and are 50 per cent. stronger, and the outer layers, which are almost invariably made of lower-grade material (see paragraph 37) have often a specific capacity of three and more, a very poor insulation resistance, and strangely enough up to three times the puncture strength of some samples of better class compounds.

65. The layers of insulation on such cables are arranged in the opposite order of capacity to the most efficient, and are only enabled to stand because the vulcanised compound rubber has a sufficiently uniform texture and a high dielectric strength (see Fig. 22). I think there is no question that, bulk for bulk, the best vulcanised rubber is stronger than the best impregnated paper, and its day will come when really high pressures are used (see Fig. 21), but just now it needs all its dielectric strength to compete in cost at present prices. It is chiefly on armoured cables that their lesser diameter results in such a saving of steel tape as to allow rubber cables to win in the price competition.

66. It may be possible to grade paper cables by "loading" the paper with barytes, clay, gypsum, etc., but it is not safe to prophesy whether or not the dielectric strength of loading materials, applied as they would be in powder form, would allow of their utilisation with advantage. A few simple experiments will solve this, however, and I have made arrangements with the courteous proprietor of the Hele Paper Co., S. Devon, to obtain a large number of samples of known composition.[1]

67. At present it will be found that rubber-covered H.T. cables have as much as double the capacity of fibre cables. This is due (i) to the specific capacities being as 3 to 2, and (ii) to the superior dielectric strength of rubber which allows the conductors to be placed nearer together. In non-concentric cables this capacity can be diminished by adding, if required, a bed or worming of jute, etc., and the reduction can be more cheaply done with rubber than if there is to be a coat of lead over each wire, which is the safest way with 3-phase hygroscopic cables other than feeders.

[1] I am also indebted to M. Champin (Paris) and Messrs. Crompton and Messrs. Fletcher for samples of excellent thin paper, on which I have made innumerable tests.

68. *Capacity of a Three-Wire Cable.*—I do not think there is any simple manner of calculating the capacities of lead-covered, three-wire, non-concentric cables.[1] In a particular experiment an approximation was got as follows:—

The capacity of two parallel wires laid on a solid system, if not lead-covered but buried in the insulator, is per unit length—

$$= \frac{K}{2 \log (a \sqrt{a^2 - 1})} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where K is the specific inductive capacity of the insulator, and—

$$a = \frac{(d^2 - R^2 - R'^2)}{2 R R'},$$

and where d is the distance between the centres of the wires, whose radii are R, R'.[2]

69. Where there is a lead sheath at a distance equal to the distance between the surfaces of the wires, and further a third wire in the solid dielectric, 10 per cent. must be added to get the capacity between any two. Lastly, the capacity-current for all these wires will be approximately 33 per cent. greater than the capacity-current calculated for two wires as above.

70. *Capacity of a Two-Wire Cable* is given by G. W. Patterson[3] as follows:—

If the radius of each wire be R;
If the least thickness between wires be d;
If the spec. dielectric capacity = K;

[1] *Capacity.*—B. Breisig (*Elektrotech. Ztschr.*, 20. pp. 127–131, 1899). Now that multiphase work is making the concentric cable less prominent than heretofore in H.T. transmissions, a formula for the capacity of twisted wires is of value, even though it only gives an approximation. A two-wire cable may be regarded as three condensers in parallel, and Breisig gives an expression for more wires. The capacity K is approximately given by the formula—

$$K = c' + (1 - K) c.$$

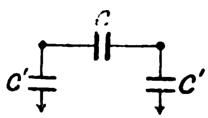

FIG. 6.

[2] J. B. Pomey, *Ecl. Electr.*, 19. pp. 131–133, 1899.
[3] *Phys. Rev.*, 3. pp. 309–313.

Then the capacity in microfarads per centimetre length is

$$= (1206 \times 10^{-10}\,K) \div \log\left(\frac{\sqrt{(4Rd + d^2)} + d}{\sqrt{(4Rd + d^2)} - d}\right).$$

It is interesting here to point out that the capacity of the lines of an overhead three-phase system may, according to Perrine and Braum, be considered as that of three condensers connected between the wires in a star and not a mesh pattern. If the centres of the wires are at the corners of an equilateral triangle whose side is d, and if r be the radius of the wires whose length is L, the charging current can be calculated by supposing three condensers, each of capacity C, where—

$$C = \frac{0{\cdot}0388\,L}{\log_{10}\frac{d}{r}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

microfarads connected starwise between the mains. If the capacity be considered as mesh connected, then the charging current would be $\sqrt{3}$ times the charging current of a single phase; if star connected, the current is $\sqrt{\frac{2}{3}}$ of current on a single-phase line.

71. If my "graded" cable has any utility, it will be interesting to know its capacity, which cannot, of course, be calculated according to the ordinary law; it works out to be simply inversely as the radial depth of insulation in all single and concentric cables (see equation No. 10 below), and the fall of potential curve is a straight line (see equation No. 11 below).[1]

[1] Let O A = inner radius of dielectric = r.
" O B = outer radius of dielectric = R.
" V_0 = difference of potential between inner and outer conductors.
" V = difference of potential between any point P in the dielectric and the outer conductor.
" O P = ρ.
" Q = charge on unit length of inner conductor.
" K = specific inductive capacity of dielectric.
" C = capacity per unit length of cable.

If K is constant—

$$\frac{V}{V_0} = 1 - \frac{\int_r^\rho \frac{d\rho}{K\rho}}{\int_r^R \frac{d\rho}{K\rho}} = 1 - \frac{\log \rho - \log r}{\log R - \log r};$$

I am indebted to Mr. C. S. Whitehead for the following:—

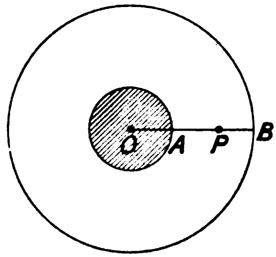

FIG. 7.

or

$$\frac{V}{V_c} = 1 - \frac{\log \rho / r}{\log R / r} \quad \ldots\ldots\ldots \quad (6)$$

$$C = \frac{K}{2 \log R / r} \quad \ldots\ldots\ldots \quad (7)$$

If K is the function of ρ—

$$C = \frac{1}{2 \int_a^b \frac{d\rho}{K\rho}} \quad \ldots\ldots\ldots \quad (8)$$

$$\frac{V_o - V}{V_c} = \frac{\int_r^\rho \frac{d\rho}{K\rho}}{\int_r^R \frac{d\rho}{K\rho}}$$

If we put $\frac{1}{m} = \int_r^R \frac{d\rho}{K\rho}$, which is a constant.

$$\frac{V_o - V}{V_o} = m \int_r^\rho \frac{d\rho}{K\rho} \quad \ldots\ldots\ldots \quad (9)$$

If K varies as the slope of (6),

we have slope $= -\frac{1}{V_o} \frac{dV}{d\rho} \propto \frac{1}{\rho}$;

therefore we may put $K = \frac{n}{\rho}$, where n is a constant.

Therefore from (3) the capacity per unit length of "graded" cable is

$$C = \frac{1}{2 \int_r^R \frac{d\rho}{n}} = \frac{n}{2(R-r)} \quad \ldots\ldots \quad (10$$

72. *Magnitude of Capacity.*—From the point of view of regulation alone, a line should be designed for the smallest possible capacity-current without any attempt to balance the line capacity against the lag, because the inductive drop varies as the load, whereas the capacity is a constant, so that no appreciable economy of regulation is obtained.

F. A. C. Perrine[1] recommends that at substations reactance coils be used to regulate the voltage instead of regular transformers, because they will neutralise the capacity-current and diminish the generator-current and line losses at no load.

73. *Value of Capacity.*—In spite of the apparent feeling in this country against it, it is difficult not to be favourably impressed by the advantages of capacity in the cables of a power system. When we consider that (1) hysteresis and other dielectric losses are small compared to the inefficiencies of the mechanical and electrical generators, that these losses do not necessarily bear any such regular proportion to the capacity as is implied by the use of the term "power-factor," that they may be reduced by using a sine-wave, that they

For the fall of potential in this case we have—

$$\frac{1}{m} = \int_r^R \frac{d\rho}{n} = \frac{R-r}{n};$$

therefore $m = \dfrac{n}{R-r}$;

therefore the fall is given by (4)—

$$\frac{V_0 - V}{V_0} = \frac{n}{R-r} \int_r^{\rho} \frac{d\rho}{n} = \frac{\rho - r}{R-r} \quad . \quad . \quad . \quad . \quad . \quad (11)$$

therefore the curve is a straight line.

[1] *Elect. Rev.*, N.Y., 37. pp. 152–153, Aug. 15, 1900. This, however, is by no means final. Dr. de Hoor favours a large capacity (*Electrician*, Feb. 8, 1901) from the point of view of the efficiency of the generators and armature reactions, preferring a leading current to the lag usually found in practice. If this view should receive full corroboration, concentric cables can be so connected up as to afford much larger capacities than have hitherto been usual. For although the great charm of a concentric cable is the fact that the potential between the outer and earth is *nil*, whether the outer be earthed or not if its ends be free, and that it may be kept nearly *nil* when lamps are connected by earthing the outer, thereby reducing the thickness of insulation on the larger diameter wire, and securing that only one pre-arranged pole of the alternator shall be alternating largely in potential above and below the earth's potential, these merits may be foregone, and by cross-connecting the outer and inner conductors in segments of equal length, we may not only make the capacity on the two mains equal but very much greater than before it. Andriessen quotes a case where a 65 per cent. increase was so obtained.

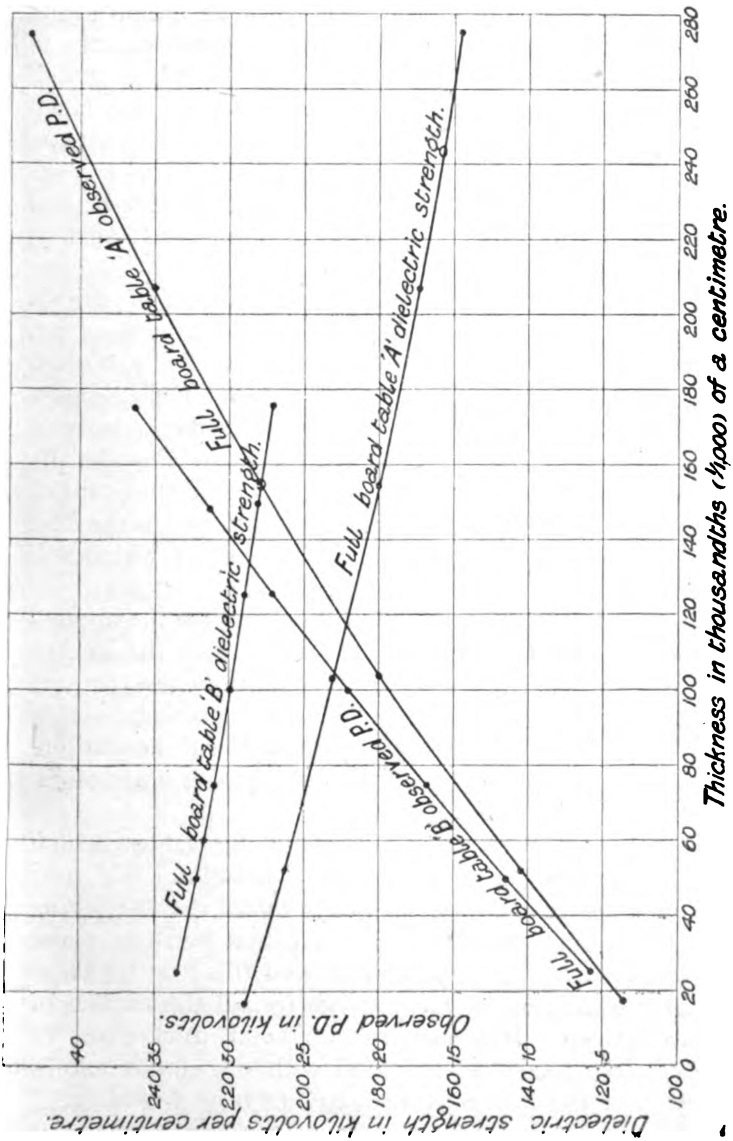
Full board table 'A' observed P.D.
Full board table 'B' dielectric strength.
Full board table 'A' dielectric strength.
Full board table 'B' observed P.D.
Observed P.D. in kilovolts.
Dielectric strength in kilovolts per centimetre.
Thickness in thousandths (1/1000) of a centimetre.
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
5
10
15
20
25
30
35
40
100
120
140
160
180
200
220
240

FIG. 8.

may be made smaller by purifying the dielectric (Threlfall) and further diminished by obtaining the minimum slope of potential by "grading." (2) The generator and line losses are diminished by improving the power-factor (Kapp found 3·5 per cent. difference of loss between power-factors of 1·0 and 0·8 in a generator alone). (3) The initial cost of the generator is diminished by an amount which may reach 20 per cent. by a power-factor of 0·8 instead of 1.0. (4) The cost of a capacity of 1 microfarad for 10,000 volts is not less than £60, whereas in the cable it can be had for nothing. (See also C. V. Drysdale, *Electrician*, April 5, 1901, p. 890.)

74. *Radial Depth of Dielectric.*—Knowledge of this is practically the foundation of the power-cable makers' art, just as in telephone cable making the amount of elbow room to give any size of wire with any given number of neighbours is the cardinal fact which is so rarely discussed outside of the manufacturers' circle. It is interesting to consider the subject of "radials" at some length, not from the point of view of small conductors and small voltages, but in the case of large conductors and high pressures, both of which will be of interest in the immediate future.

If we double the radial depth, can we double the applied pressure between conductors? If we increase the size of conductor, must we increase the radial thickness for the same volts? The tendency has up to the present been to answer both questions affirmatively, though with hesitation; the curve of gradients points to an opposite conclusion. How, then, does the price vary?

75. We must commence by giving the values which practice has fixed to a number of variables. We may suppose the insulating material has a *constant volt-resisting quality* per centimetre thickness measured between plane surfaces. Trowbridge (1898) has proved this true for large thicknesses of air, and T. Gray (1898) for all thicknesses of paraffined paper. It is not true for small thicknesses of substances like paper impregnated with oil, empire cloth, mica, etc., but the law is known, having been investigated by T. Gray and others. Some idea of the law is given by the curves Figs. 8, 9, 10, 11, 12.

76. It will be seen that with the exceptions of paraffined paper and air, the disruptive strength is great when the

testing plates are near together, and diminishes according to an approximate hyperbolic law with increasing thickness, reaching after a certain thickness, a nearly constant lowest value. One would think that this lowest value might be

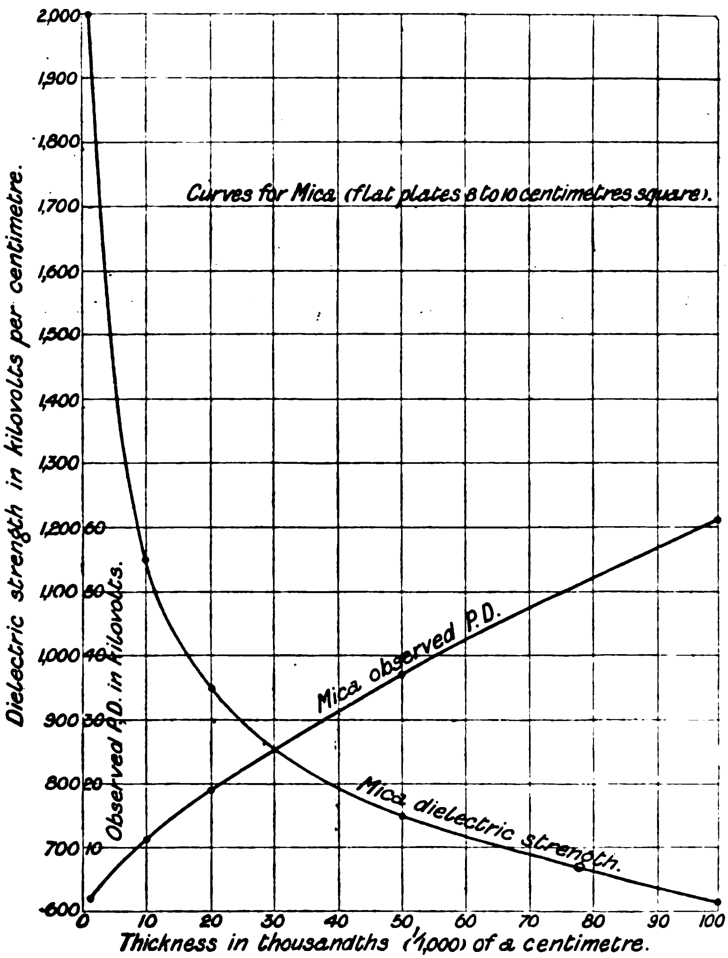

FIG. 9.

taken as safe for cable-making, but on referring to practice we find that a factor of safety of 10 to 20 is used, and this brings us well on towards the flat part of the curves. It is unnecessary to say that every nerve has been strained to reduce the factor by seeking for cleanliness, uniformity of

material, absence of metal particles, etc. The effect on price of reducing this factor of safety, or what eventually comes to the same thing, increasing the available disruptive strength of the material applied, is given by Fig. 13, which takes the example of a 37/14 at various voltages from 3,000 upwards, and shows, for example, that halving the factor of safety will make a thirtyfold economy of insulation at 30,000 volts, and a fivefold economy at 10,000 volts. Had the effect of thickness in weakening the dielectric been considered, the advantage of a strong dielectric which is not weak for any thickness would have appeared greater.

77. Until we are quite clear that such phenomena as Mr. Duddell showed us in his admirable paper on the 13th December, 1900, do not, as I believe they do not, often occur in practice, we should be rash to diminish our factor of safety much below 10, as it is difficult to secure that carbon-break switches and other precautions shall be universally used.

78. Fixing then, as we unfortunately must, on the dielectric stress which has so far been found in good practice to be the maximum allowable, and which is the same for fibrous cables as Mr. Swinburne found for condensers, namely, about 20,000 volts per centimetre,[1] we must consider the effect produced upon the "radial" depth of insulation by varying the diameter of the conductor. We are accustomed with low tensions to increase the "radial" with increasing thickness of copper according to some such rules as those of the Institution.[2]

79. This custom is the outcome of experience, and is chiefly based on obtaining the mechanical rigidity necessary with the increasing weight and stiffness of copper as well as keeping above the somewhat arbitrary 300 megohm standard (on 19/16 cables).

80. With high tensions, disruptive strengths must eventually be the dominant factor, and the thickness of the insulation be determined[3] by assuming that manufacture is so improving

[1] This is less than the dielectric strength of air if we consider the working maximum pressure to be the greatest to which the cable is subjected, and disregard pressure oscillations of unknown origin. As a consequence, the danger of air bubbles has not in the past had the consideration it will have with improved cable manufacture and high voltage. Layers of air, unlike bubbles, may not be a disadvantage if the layers be thin, for a very different reason.

[2] Add 30 mils to one-tenth the diameter of the cable.

[3] This subject has been concisely dealt with by Mr. Swinburne (Engineering Conference, June 7th, 1899) in a paper that was not adequately recognised at the time, owing to the author's being unable to read it himself.

that the dielectric is applied in a more and more homogeneous state, clean, free from spangles, dirt, moisture and bubbles, and that for high potentials it will be chiefly necessary to consider the maximum pressure and not

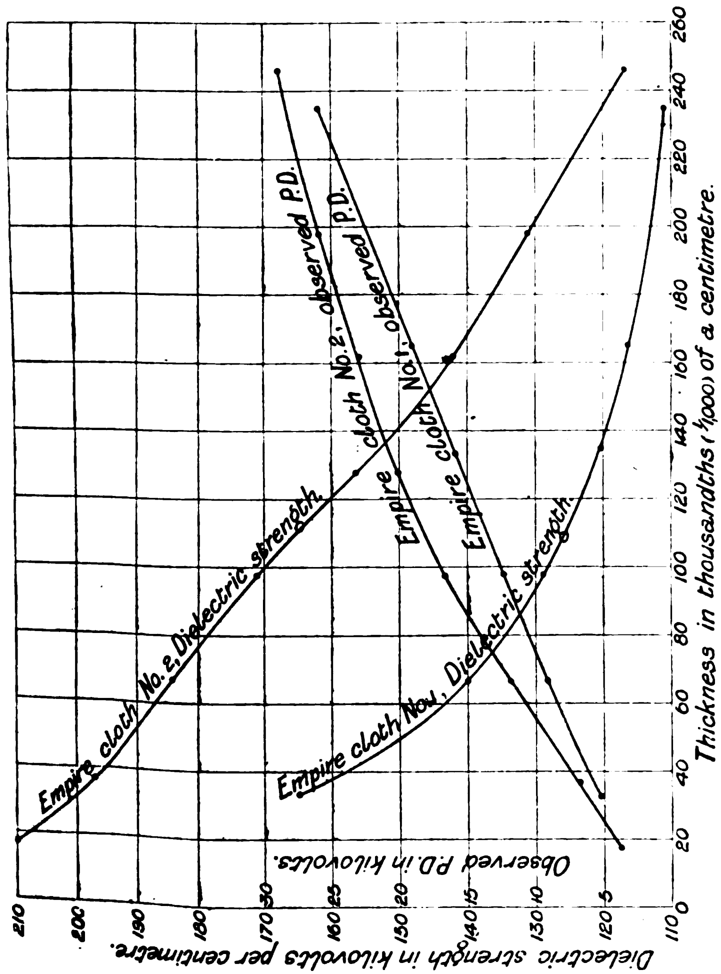

FIG. 10.

mechanical restrictions. We will therefore determine the radial depth of insulation by the maximum potential gradient which the materials will stand, and give prices to the cables so determined for both normal and abnormally large

I will take the liberty to use it wholesale, both now and later on. I am very greatly indebted to him for help in the course of this paper and for the general idea of the slope of potentials in cylindrical insulators.

pressures and conductors. The formula which gives the radius R of insulation for a given voltage E is given by Mr. Swinburne[1]:—

$$\frac{dE}{d\rho} = \frac{r}{\rho}S \quad \therefore \log R = \frac{E}{rS} + \log r \quad . \quad . \quad (12E)$$

$\therefore E = S\,r\,\mathrm{Log}_\epsilon \frac{R}{r}$, where S is the maximum allowable stress per centimetre, and r the radius of the conductor in centimetres.

81. This formula follows Maxwell (see Appendix VI.) in assuming that dielectric strength may be measured by the electric intensity when the dielectric ruptures.

There is some possibility that the dielectric strength within the materials is also constant even for small thicknesses, but that owing to the skin resistance between metal and dielectric, and possibly between the various layers of insulation, the measurements of P.D. have come out disproportionately high. The suggestion of a skin resistance I owe to Prof. Perry.

The remaining constants are as follows:—

82. *Copper* is taken at £100 a ton (or 11d. per lb.), a price which is rather too high. This is to cover market fluctuations. I justify its use because the deductions and curves which follow are only comparative, and the effect on the total price of the various insulation thicknesses outweighs the price of copper on both small and large sizes; for example, between 15,000 kilowatts and 30,000 kilowatts the price of cable is nearly constant, although the copper varies from 0·53 sq. in. to 1·5 sq. in. Another reason for taking a high price for copper is that the labour of handling and jointing will depend on the weight of the cable even though the radial thickness of insulation may go down. Lastly, the decimal figure £100 is easy to correct if a more accurate estimate is available. The £100 is made up as follows. G.M.B. Copper in the market £78, cost of wire drawing £8, stranding £5, shop charges and administration £10 per ton.

83. *Insulation* £50.—This price is too low for rubber cables, but as it is well known that the cost of fibre

[1] J. Swinburne's paper (before Eng. Society, 1897) on Electrical Transformation.

together with its lead is of the same *order* as rubber, it will follow that the general trend of the curves holds for rubber also, only the maxima and minima will be more marked for any class of insulation dearer than I have selected unless the disruptive strength is correspondingly greater. Paper £35 a ton, impregnating oil £7, labour £10, administration, etc., £19.

84. *Lead.*—£25 a ton was taken to allow for the labour of lead-covering, which is high. A thickness of 0·125

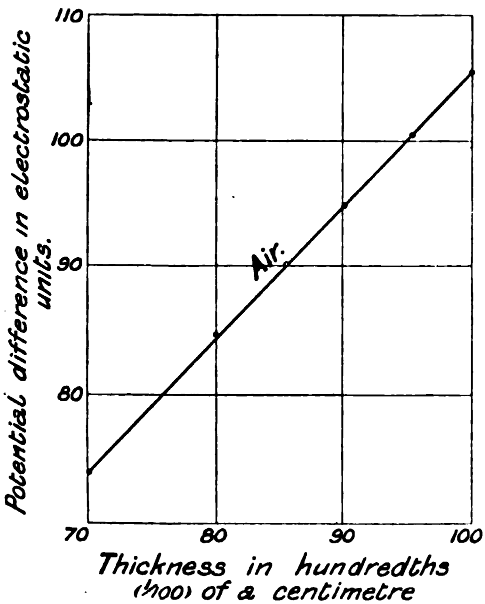

FIG. 11.

inches was taken in all cases. This thickness is rather small for large cables, which sometimes takes 0·15 or 0·18 inches. If this increase of lead had been allowed for, the rate at which the cost of cables increases with increase of output would have been still further diminished, within practical limits of copper section, but the character of the curves would not be altered, only accentuated. (Best Spanish lead £15 a ton, labour £3, administration £6 a ton.)

85. *The Current Densities* necessary to get the same loss,

(10 per cent.) of power in the 47-mile transmission at the various voltages are :—

40,000	30,000	25,000	20,000	15,000	10,000 volts.
1,000	750	625	500	375	250 amperes per sq. in.

86. *The Labour* of applying insulation or lead is not a price per pound, but rises according to a different curve not a straight line. It is easy, though laborious, to apply a correction, and it will be found not to affect the general tendency of the curves.

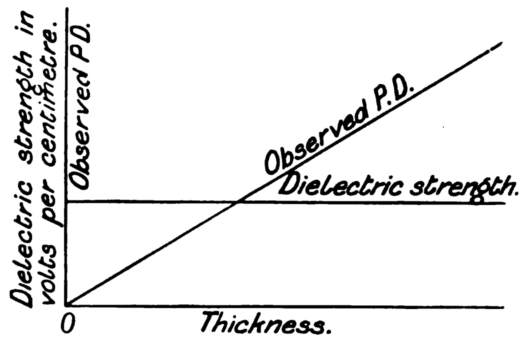

FIG. 12.—Paraffined Paper.

87. *The Frequency* has been supposed low.

The curves on Figs. 16, 17, 18, 20, show that increasing the diameter of the conductor may produce such a diminution of dielectric thickness as to lessen the total price, and it follows that when this happens, it is cheaper to use hollow than solid conductors for certain sizes of wire, namely, for all those sizes where I have dotted the curve of price.[1]

The *frequency* has been supposed chosen very low, so that the increased impedance of the conductors may be disregarded for all the practical sizes ; nevertheless the necessity for low frequency in the larger sizes is shown by

[1] From this, it follows that (leaving out of account high frequencies where there are special advantages for a hollow conductor over a solid one) in high-tension work a considerable gain may be made by using aluminium instead of copper because the aluminium has a greater diameter by 28 per cent., and this gain is the greater for certain sizes and pressures the more expensive the insulating material. I owe this suggestion to Mr. Swinburne.

It is further enhanced by the ease of handling, 50 per cent. less weight for equal conductivity, and in cables the difficulties of soldering joints, and the irregular tensile strength complained of by Mr. Gavey (Jan. 10, 1901) are more easily surmounted than in overhead wires.

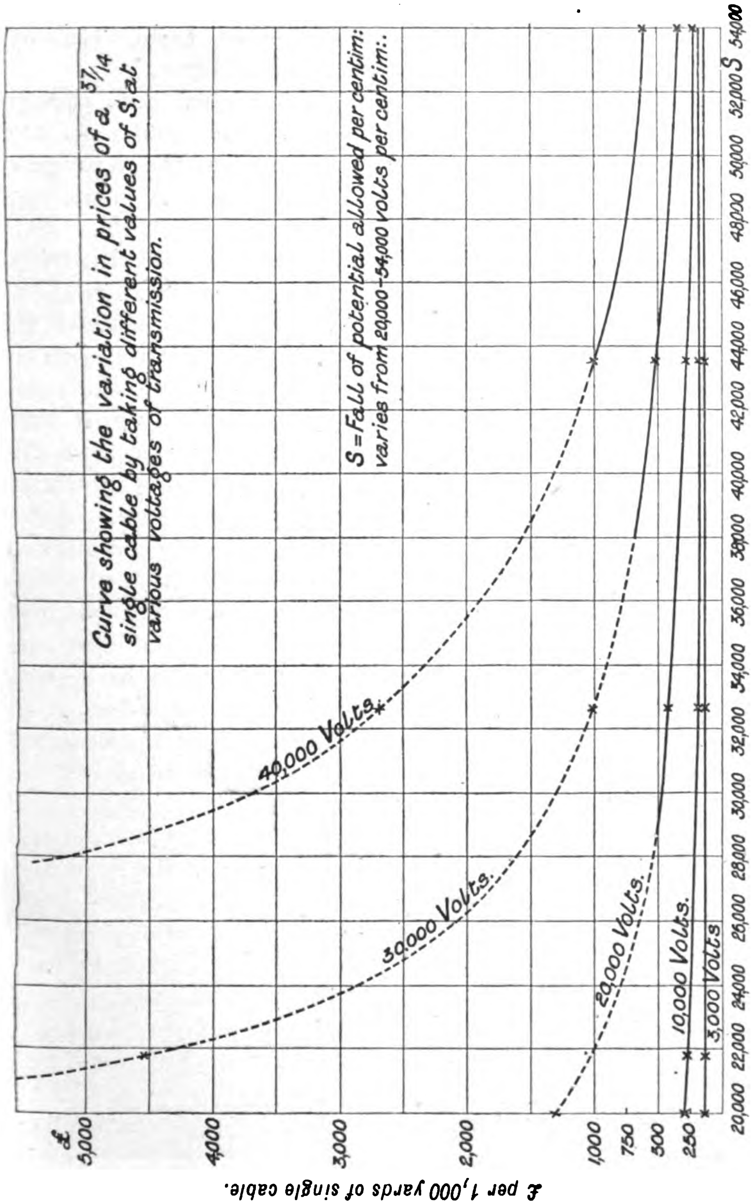

FIG. 13.—The economy of increasing the disruptive strength of insulation.

FIG. 14.—The section of copper being constant, we may take the power which may be transmitted as proportional to the square of the voltage.

It is to be noted that were a high value of S allowable (say, 50,000 volts per cm.) at *d*, the price of an insulated 37/14 cable for different voltages increases much less rapidly than the voltage, and therefore very much less rapidly than the power which such a cable could transmit. Therefore where S is high, it pays to use high-pressure cables up to say 30,000 volts. When S may not exceed 20,000 volts per cm. the price rises prohibitively with the voltage, that is at a greater rate than proportional to the power.

Mr. Mordey's well-known tabulation of Lord Kelvin's formula quoted in an appendix to this paper.

88. *Skin Effect.*—In the absence of any but meagre evidence to the contrary, the voltage in the insulation next to the conductor is taken as being equal to the voltage of the conductor itself, although it probably is somewhat lower.

89. *Shape of Conductors.*—These are supposed cylindrical, and free from points or projections of small curvature.

On the above assumptions, the relation between the radius of the copper conductor and the radial depth of insulation is shown in curve 15, from which it is seen that the thickness of insulation falls at first rapidly and then steadily as the conductors get larger and larger, and this answers question one in the negative. Doubling the radial depth by no means allows of doubling the pressure.

90. *Three-phase or Single-phase.*—Mr. Swinburne worked out the thickness of insulation for the four methods of transmission, *i.e.*, direct-current, and with currents of one, two, and three phases, but with a fixed weight of copper and fixed current density to be used in all cases, and I think his results should be considered here. I therefore give two tables of 16 and 17 estimates for his cables on the basis of the assumed constants numbered 82, 83, 84, 86, 87, 88, and 89 above.

TABLE I.

Current density fixed at 200 amperes per sq. c.m. and total copper kept constant, namely, 2 sq. cms. for lead and return. Maximum allowable slope of voltage in the insulation = 20,000 volts per cm.

System.	Amperes per Wire.	Max. Volts for R.	Eff. Volts = e.	Eff. Amps. = i.	Power Formula.	K.W. put into cable.	Cost per 1,000 yds.	K.W. per £1.	Description of Cables.	% Loss of power on a 10-mile transmission.
Case I.							£			
Direct ...	200	15,000	30,000	200	$e\,i$	6,000	654	9·17	Two single cables	3·7
Single-phase	200	15,000	21,210	200	$e\,i$	4,250	654	6·5	Two single cables	5·2
Bi-phase ...	117, 117, 166	15,000	10,600	117	$2\,e\,i$	2,480	836	2·97	Two concentrics	8·9
Tri-phase ...	133	15,000	18,400	77	$3\,e\,i$	4,250	1,072	3·9	Three single cables	5·2
Case II.										
Direct ...	200	15,000	15,000	200	$e\,i$	3,000	411	7·3	One concentric	7·4
Single-phase	200	15,000	10,600	200	$e\,i$	2,125	411	5·18	One concentric	10·4
Bi-phase ...	117, 117, 166	15,000	10,600	117	$2\,e\,i$	2,480	836	2·97	Two concentrics	8·9
Bi-phase ...	117, 117, 166	21,210	10,600	117	$2\,e\,i$	2,480	1,633	1·52	One triple concentric	8·9
Tri-phase ...	133	15,000	10,600	77	$3\,e\,i$	2,450	733	3·34	One triple concentric	9·0
Tri-phase ...	133	15,000	10,600	77	$3\,e\,i$	2,450	768	3·19	Two concentrics	9·0
Case III.										
Direct ...	200	15,000	15,000	200	$e\,i$	3,000	411	7·3	One concentric	7·4
Single-phase	200	15,000	10,600	200	$e\,i$	2,125	411	5·18	One concentric	10·4
Bi-phase ...	117, 117, 166	10,600	7,500	117	$2\,e\,i$	1,760	398	4·42	Two concentrics	12·6
Bi-phase ...	117, 117, 166	15,000	7,500	117	$2\,e\,i$	1,760	681	2·58	One triple concentric	12·6
Tri-phase ...	133	15,000	10,600	77	$3\,e\,i$	2,450	768	3·19	Two concentrics	9·0
Tri-phase ...	133	15,000	10,600	77	$3\,e\,i$	2,450	733	3·34	One triple concentric	9·0
Tri-phase ...	133	8,670	10,600	77	$3\,e\,i$	2,450	407	—	Three single cables	9·0

TABLE II.

Current density fixed at 200 amperes per sq. cm., and total copper kept constant, viz., 2 cm.² for lead and return. 10,000 Volts maximum; S = 40,000 volts per cm.

System.	Amperes per Wire.	Max. Volts for calculating Radials.	Eff. Volts = *e*.	Eff. Amps. = *i*.	Power Formula.	K.W. put into cables.	Cost per 1,000 yards insulation at £100 per ton.	K.W. per £1.	Description of Cables.	Cost per 1,000 yards insulation at £50 per ton.	% loss in 10 miles.
Case I.							£			£	
Direct ...	200	10,000	20,000	200	*c i*	4,000	292	13·7	Two single cables	265	5·7
Single-phase	200	10,000	14,140	200	*e i*	2,828	292	9·7	Two single cables	265	8·13
Bi-phase ...	117, 117, 166	10,000	7,070	117	2 *e i*	1,655	278	5·95	Two concentrics	254	13·7
Tri-phase ...	133	10,000	12,250	77	3 *e i*	2,828	334	8·45	Three single cables	297	8·13
Case II.											
Direct ...	200	10,000	10,000	200	*e i*	2,000	230	8·7	One concentric	217	11·35
Single-phase	200	10,000	7,070	200	*e i*	1,414	230	6·15	Two concentrics	217	16·06
Bi-phase ...	117, 117, 166	10,000	7,070	117	2 *e i*	1,655	278	5·95	Two concentrics	254	13·7
Bi-phase ...	117, 117, 166	14,140	7,070	117	2 *e i*	1,655	300	5·52	One triple concentric	258	13·7
Tri-phase ...	133	10,000	7,070	77	3 *e i*	1,635	273	5·98	One triple concentric	242	13·88
Tri-phase ...	133	10,000	7,070	77	3 *e i*	1,635	282	5·8	Two concentrics	257	13·88
Case III.											
Direct ...	200	10,000	10,000	200	*e i*	2,000	230	8·7	One concentric	217	11·35
Single-phase	200	10,000	7,070	200	*e i*	1,414	230	9·15	One concentric	217	16·06
Bi-phase ...	117, 117, 166	7,070	5,000	117	2 *e i*	1,170	251	4·65	Two concentrics	237	19·4
Bi-phase ...	117, 117, 166	10,000	5,000	117	2 *e i*	1,170	253	4·62	One triple concentric	230	19·4
Tri-phase ...	133	10,000	7,070	77	3 *e i*	1,635	282	5·8	Two concentrics	257	13·88
Tri-phase ...	133	10,000	7,070	77	3 *e i*	1,635	273	5·98	One triple concentric	242	13·88

N.B.—Cost of Insulation taken as double the normal price in the 8th column to allow for the dielectric strength being double.

91. It will be seen that three-phase currents allow of more power being transmitted for equal weights of bare

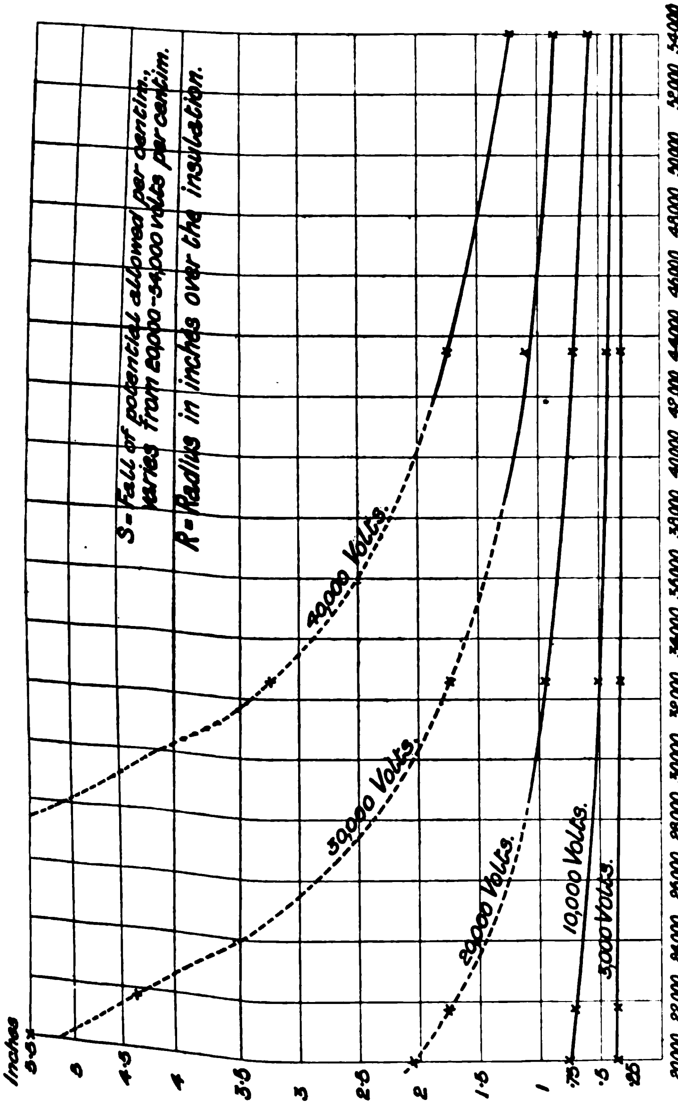

FIG. 14.—Curve showing the reduction of depth of insulation on a 37/14 when the dielectric strength is increased but kept homogeneous. S Gradients in volts per cm.

FIG. 14 shows that if 30,000 volts or 40,000 volts is likely to be the limit of pressures for structural reasons in alternators, switchboards, &c., there is no great economy on cables to be made by increasing the dielectric strength alone beyond 50,000 volts per cm., and experiments need not be made in that direction beyond that limit.

TABLE II.

Current density fixed at 200 amperes per sq. cm., and total copper kept constant, viz., 2 cm.² for lead and return. 10,000 Volts maximum ; S = 40,000 volts per cm.

System.	Amperes per Wire.	Max. Volts for calculating Radials.	Eff. Volts = e.	Eff. Amps. = i.	Power Formula.	K.W. put into cables.	Cost per 1,000 yards insulation at £100 per ton.	K.W. per £1.	Description of Cables.	Cost per 1,000 yards insulation at £50 per ton.	% loss in 10 miles.
Case I.							£			£	
Direct ...	200	10,000	20,000	200	$e\,i$	4,000	292	13·7	Two single cables	265	5·7
Single-phase	200	10,000	14,140	200	$e\,i$	2,828	292	9·7	Two single cables	265	8·13
Bi-phase ...	117, 117, 166	10,000	7,070	117	$2\,e\,i$	1,655	278	5·95	Two concentrics	254	13·7
Tri-phase ...	133	10,000	12,250	77	$3\,e\,i$	2,828	334	8·45	Three single cables	297	8·13
Case II.											
Direct ...	200	10,000	10,000	200	$e\,i$	2,000	230	8·7	One concentric	217	11·35
Single-phase	200	10,000	7,070	200	$e\,i$	1,414	230	6·15	Two concentrics	217	16·06
Bi-phase ...	117, 117, 166	10,000	7,070	117	$2\,e\,i$	1,655	278	5·95	Two concentrics	254	13·7
Bi-phase ...	117, 117, 166	14,140	7,070	117	$2\,e\,i$	1,655	300	5·52	One triple concentric	258	13·7
Tri-phase ...	133	10,000	7,070	77	$3\,e\,i$	1,635	273	5·98	One triple concentric	242	13·88
Tri-phase ...	133	10,000	7,070	77	$3\,e\,i$	1,635	282	5·8	Two concentrics	257	13·88
Case III.											
Direct ...	200	10,000	10,000	200	$e\,i$	2,000	230	8·7	One concentric	217	11·35
Single-phase	200	10,000	7,070	200	$e\,i$	1,414	230	9·15	One concentric	217	16·06
Bi-phase ...	117, 117, 166	7,070	5,000	117	$2\,e\,i$	1,170	251	4·65	Two concentrics	237	19·4
Bi-phase ...	117, 117, 166	10,000	5,000	117	$2\,e\,i$	1,170	253	4·62	One triple concentric	230	19·4
Tri-phase ...	133	10,000	7,070	77	$3\,e\,i$	1,635	282	5·8	Two concentrics	257	13·88
Tri-phase ...	133	10,000	7,070	77	$3\,e\,i$	1,635	273	5·98	One triple concentric	242	13·88

N.B.—Cost of Insulation taken as double the normal price in the 8th column to allow for the dielectric strength being double.

91. It will be seen that three-phase currents allow of more power being transmitted for equal weights of bare

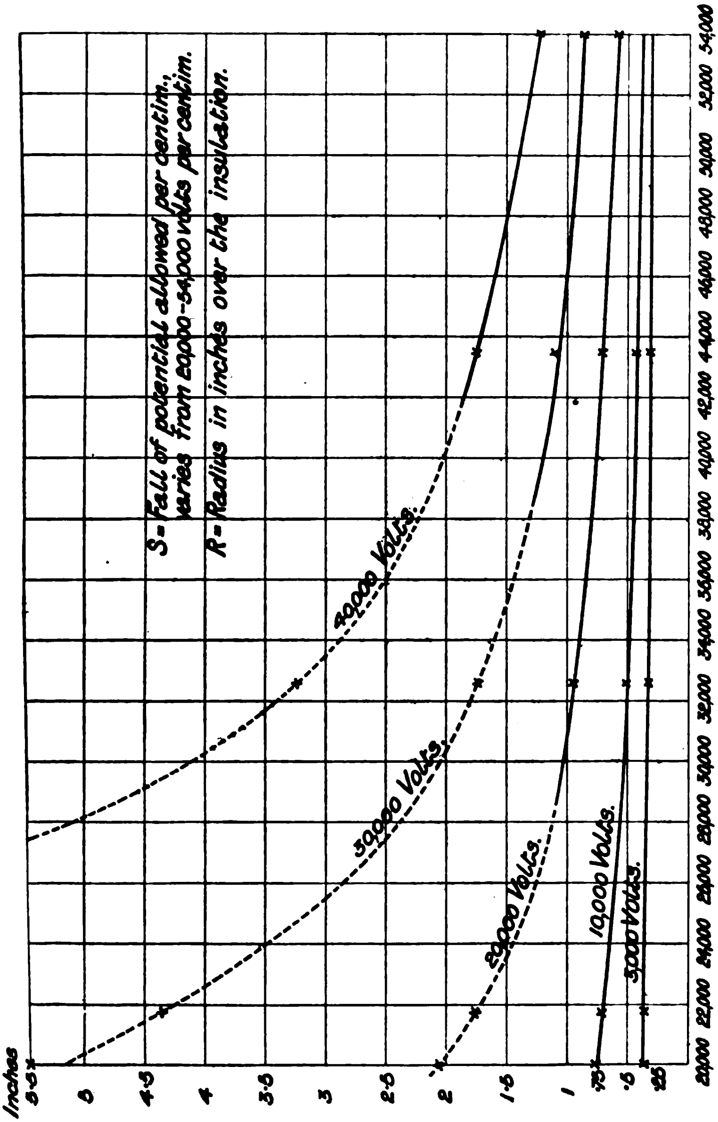

FIG. 14.—Curve showing the reduction of depth of insulation on a 37/14 when the dielectric strength is increased but kept homogeneous. S Gradients in volts per cm.

FIG. 14 shows that if 30,000 volts or 40,000 volts is likely to be the limit of pressures for structural reasons in alternators, switchboards, &c., there is no great economy on cables to be made by increasing the dielectric strength alone beyond 50,000 volts per cm., and experiments need not be made in that direction beyond that limit.

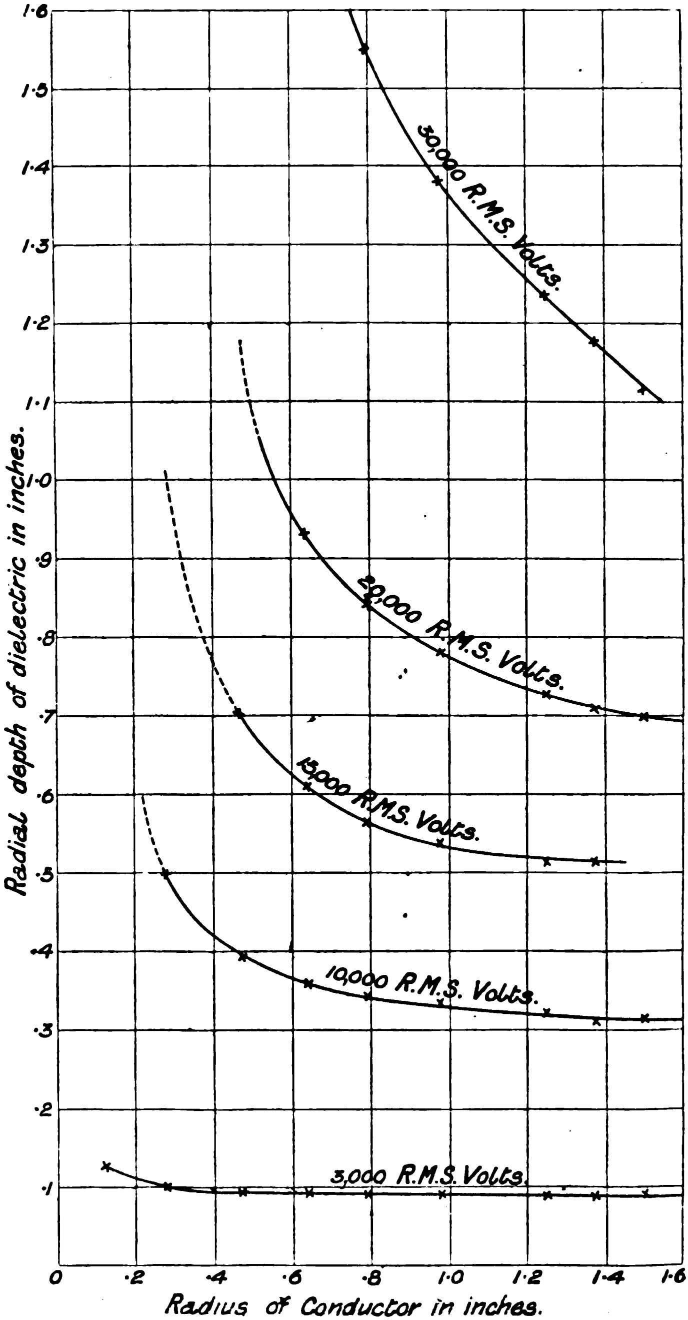

FIG. 15.—Relation between the radius of copper and the radial depth of dielectric with various voltages. Greatest slope of voltage allowable 20,000 per cm. in the dielectric. Assumed to be homogeneous.

copper [1] in every case (except one which is scarcely practicable), but in this set of examples [1] they transmit less kilowatts per pound sterling when insulated and lead-covered.

92. This consideration appears to be in favour of single-phase work for powers of from 1,500 to 5,000 kilowatts at and about 10,000 maximum volts, but it does not follow that single-phase is best.

93. On the contrary, with insulated cables considerations of price lead to the opposite conclusion to Mr. Swinburne's, who found that "his figures broadly showed that the direct- and single-phase systems are preferable as far as cost and convenience of insulation go." I think he would not have come to this conclusion if he could have got estimates for sizes of copper and voltages other than those he proposed. The broad conclusion is not allowable. The single-phase is best with small copper, cheap insulation, and large voltages: otherwise not.

94. This opposite conclusion is derived from Appendix V., where the sizes of conductors and voltages are different. It would appear from this investigation of costs that the best method of transmission and the best voltage may, in the near future, be fixed on the basis of such estimates as the present, and that for some powers and voltages single-phase may be cheapest, and for others three-phase—where covered cables must be used. £50 expended on such estimates might easily save £5,000 in cables.

It is to be noted that only round wires, lead-covered, and concentric cables have been worked out, as it is arduous work to get the radial thickness with irregular-shaped or bunched wires.

95. *The Board of Trade Rule* requires that the insulation thickness shall not be less than one-tenth of an inch for every 2,000 volts. This on large conductors would be too great a thickness according to the log law, because it implies a factor of safety of nearly 40, whereas 20 has been found to do.

96. On conductors of small radius of curvature, however, it would probably not be thickness enough were it not that with small depths of insulation most dielectrics are stronger than for great thicknesses, consequently at the comparatively

[1] See H. A. Earle, *Journ. I.E.E.*, Manchester Section, Dec. 1900.

low pressures hitherto used no inconvenience has been found.

97. Cases I., II., and III. for Tables I. and II. are the same save that the maximum volts in table I. are 15,000, and in table II. are 10,000.

Case 1.—The system earthed at a middle point, no wire to be more than 10,000 volts from earth. The direct current is then 20,000 volts and 200 amperes. The single alternating has 7,100 each side, the double alternating the same, but has its thick wire grounded and has smaller currents. The triple current has a middle point earthed, and though the difference of potential of its wires and earth never goes over 10,000 volts the difference between the wires exceeds 10,000 volts.

Case 2.—One conductor to be earthed. This is a condition that may be compulsorily enforced, and practically means concentric mains with little insulation on outside conductor. In this case the direct current has 10,000 volts and 200 amperes, the single alternating 7,100 and 200, the double alternating is as before, but the triple current comes down considerably.

Case 3 is where the difference between no two conductors exceeds 10,000 volts. In each case the leads have a total area of 2 square centimetres, and a density of 200 amperes per square centimetre.

98. It is to be noted in favour of the B.O.T. rule that air is very much stronger than the B.O.T. limit of thickness, consequently it becomes possible to introduce an air spark gap for lightning arrester of less thickness than the insulation, this being an imperative condition to obtain protection. It is also in accordance with the log law that the *points* or saw teeth of the lightning guards are specially effective in puncturing at the selected place. Were the B.O.T. thickness lowered, the lightning guards would have to be placed in oil.

99. *A 47-Mile Transmission.*—On reference to Figs. 16 and 17 it will be seen that the prices of cables have been worked out for all sizes. The size of cable is represented in square inches first and then expressed in terms of the kilowatts it

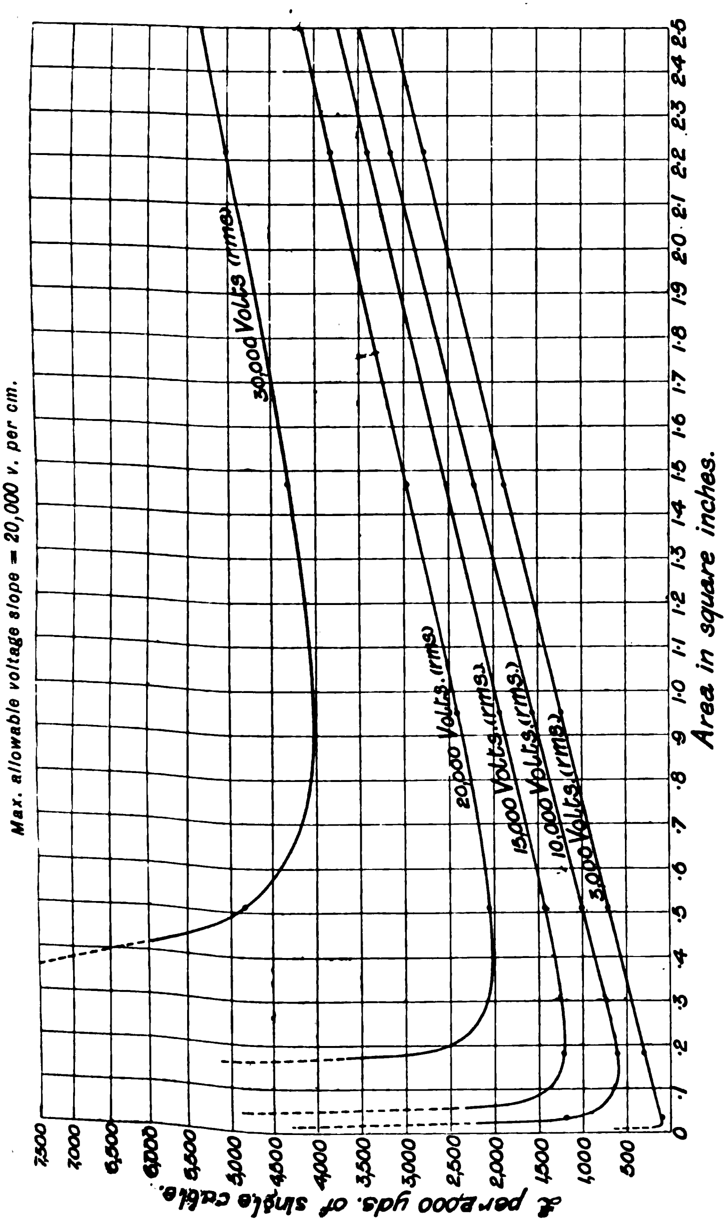
Max. allowable voltage slope = 20,000 v. per cm.
30,000 Volts (rms)
20,000 Volts (rms)
15,000 Volts (rms)
10,000 Volts (rms)
3,000 Volts (rms)
Area in square inches.
£ per 2,000 yds. of single cable.

FIG. 16.

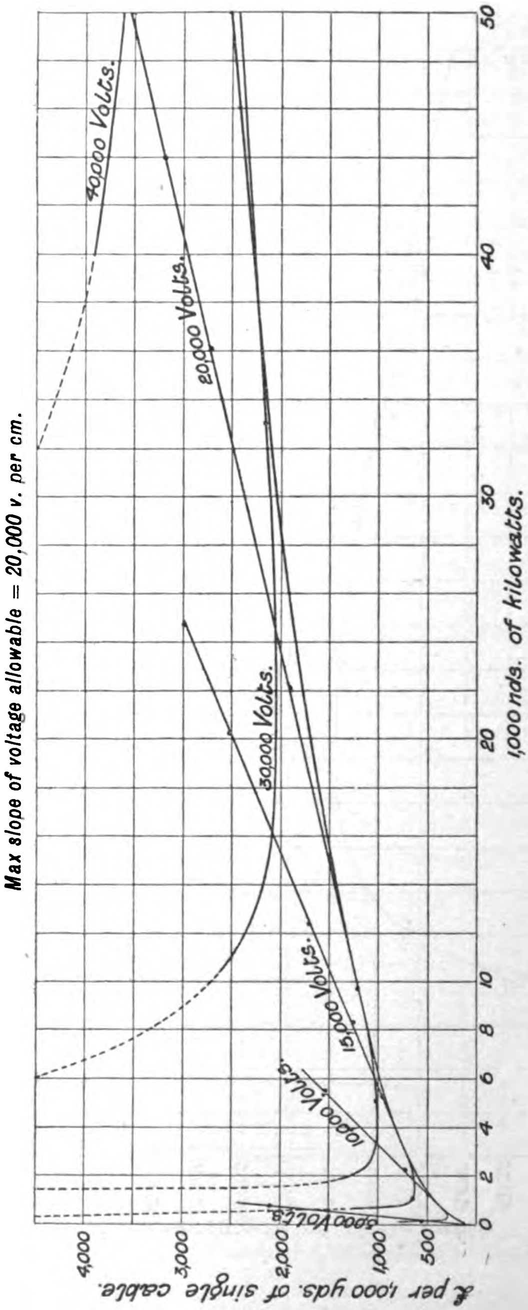
Max slope of voltage allowable = 20,000 v. per cm.
40,000 Volts.
20,000 Volts.
30,000 Volts.
15,000 Volts.
10000 Volts.
5000 Volts.
£ per 1,000 yds. of single cable.
4,000
3,000
2,000
1,000
500
0
2
4
6
8
10
20
30
40
50
1,000 nds. of kilowatts.

FIG. 17.

will carry, and when voltages vary from 3,000 to 40,000. The most expensive cable shown works out at £2,500 per 1,000 yards, and this is perhaps not a ridiculous figure to look forward to in 50 years when we see that the Blue Lakes Power Company have a transmission 36 miles long in existence at the present moment, where the conductor alone, without poles or erection, cost £1,300 a mile.[1] Nevertheless the interest chiefly lies with smaller sizes than this.

100. In working out this transmission I had begun to take into account Prof. Ayrton's modification of Kelvin's law for economy in conductors, but this portion of the paper on "radials" has grown immoderately long. So I will assume that from approximate estimates it has been decided to waste 10 per cent. of the power in the line.

101. Suppose now that 10,000 volts has been chosen as a suitable voltage for the transmission, we see from Fig. 16, that the cheapest size of cable to use is 37/14, conveying 500 kilowatts; that is 50 amperes at 10,000 volts, and this gives a copper diameter of 0·28 inches.

102. In a similar way it will be seen that for any voltage there is one particular diameter over the copper, or under the insulation which is cheapest, and if I want to transmit less power than corresponds to the solid copper, I must use a tube of copper, or in certain cases very easy to determine[2] an aluminium, or in a conceivable condition of the metal market a zinc wire. This is more than even the Aluminium Companies have hoped for.

103. If, however, we want to transmit more power than is allowed for by the cheapest conductor at 10,000 volts, had we not better increase the voltage as well as the copper, and if so, how much shall each be increased? The answer to this question is given by the bottom curve (Fig. 17) which is tangential to all voltages, and we see that it is much better not to fix upon the voltage irrespective of the relative prices of copper and insulation upon which that curve is based —a consideration which is, I believe, somewhat novel.

Suppose, for instance, the power to be transmitted is not 500, but say 2,000 kilowatts: Fig. 17 shows that the best voltage is 15,000, the best copper section by an easy

[1] J. Kershaw, "Aluminium as a Conductor," I.E.E., January 10, 1901.

[2] When diameter determined by economy of insulation is only 1·28 times the diameter of copper necessary to carry the current.

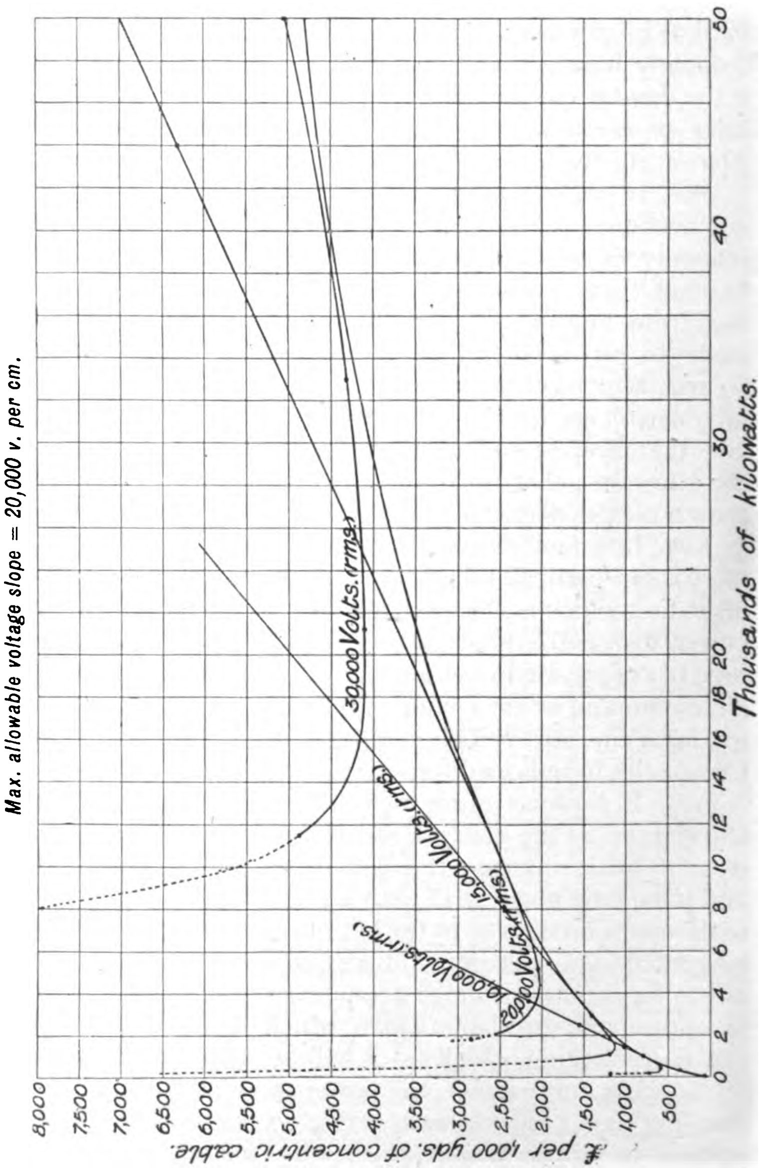

FIG. 18.—Concentric cables.

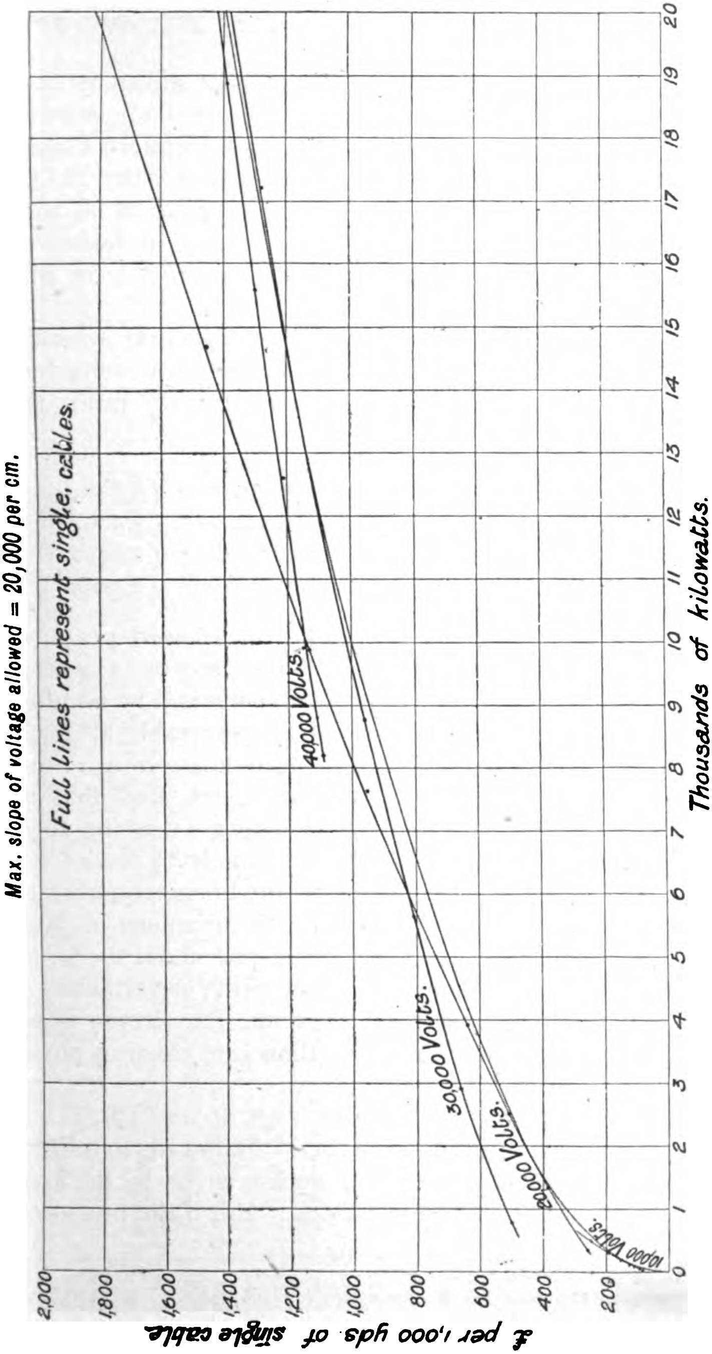

FIG. 19.—"Graded" dielectrics.

calculation is 0·334 sq. in., and the price per 1,000 yards of single cable is approximately £600.

104. There is one interesting coincidence shown by these curves. It is that at 10,000 volts, the cheapest conductor is 37/14, namely the size of the B.I.W. Co's. Deptford Cable; the radial depth of insulation is ½ inch, viz. the B.O.T. thickness for that voltage. From the 14,140 volts max. I was glad to get corroborative evidence in favour of adopting a gradient of 20,000 volts per centimetre for fibre cables in these estimates.

105. If now we turn to that part of the curve which is (because of the cost) entirely beyond practical consideration, say 50,000 kilowatts to be transmitted 47 miles, this may be effected either:

At 40,000 volts the cost per 1,000 yards is £3,650.
At 20,000 volts the cost per 1,000 yards is £3,500.
At 25,000 volts the cost per 1,000 yards is £2,600.
At 30,000 volts the cost per 1,000 yards is £2,500.

This last price is at the rate of 11*d. per kilowatt* per 1,000 yards with a 10 per cent. loss in the line on a 47-mile transmission. If we compare this with what will be admitted to be a more practical case, say of a 37/14 cable at 10,000 volts with a 10 per cent. loss in the line on a 12-mile transmission for about 1,840 kilowatts, we find that the price is £310, viz., more than 3½ times as great as the above per kilowatt per 1,000 yards of cable, namely 39 *pence*.[1]

106. In fact the larger cable is the more economical if not the more practical of the two. Its diameter is large, of course, being 3·9 inches, which is just about the largest size a modern lead press can deal with; nevertheless 50 years may see some such cables made, for already 25,000 kilowatts are generated in more than one existing power-house.

107. *The dotted portion of curves Figs.* 16 *and* 17.

It is seen that given any numbers of kilowatts to transmit the cheapest voltage at which to work is given by the lower curve, which is concave downwards. But if the pressure is

[1] In the Deptford transmission the B.I. cable cost is, I suppose, about 52 pence per 1,000 yards and per kilowatt; the loss of volts in the line is not 10 per cent. in this case, but if it were 10 per cent. instead of about 5 per cent. the cost would still be 26 pence, or twice and a half as great as in the above transmission of 50,000 kilowatts.

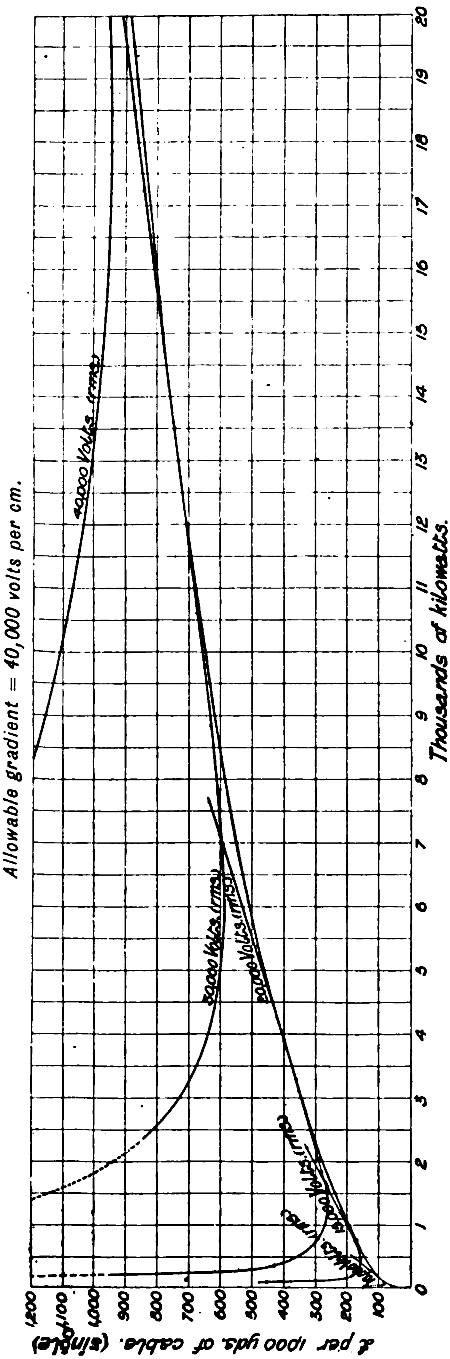
Allowable gradient = 40,000 volts per cm.
40000 Volts (r.m.s.)
30000 Volts (r.m.s.)
20000 Volts (r.m.s.)
Thousands of kilowatts.
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
£ per 1000 yds. of cable. (single)
100 200 300 400 500 600 700 800 900 1000 1100 1200

FIG. 20.

thus fixed, the subsidiary small cables which work at the same pressure are apparently exceedingly expensive, as shown by the dotted early part of the curve for each voltage.

108. This is not the case, however, and that is why those portions are dotted.

If we do not choose to pay for so thick a radial depth of insulation as will keep the maximum stress below 20,000 volts per centimetre, we can work at a less factor of safety and take the consequences. These are exemplified by enlarging on one of Mr. Swinburne's remarks on Mr. Mordey's paper on capacities.

109. If a small wire at 30,000 volts is hung in air in a dark room, a glow is visible all around it up to a certain radial distance. This is the distance up to which the air has electrically yielded, as if its "elastic limit" had been passed. It has not quite broken down like a steel bar that is "short," but like one that has passed the elastic limit and absorbs energy in stretching. The analogy is very superficial, but the brush discharge absorbs energy, as is well known.

110. I would suggest, then, that when the insulation on a cable is so thin with respect to the radius of its conductor that it allows of a fall of potential at a rate greater than, say, 100 kilovolts per centimetre,[1] it does not necessarily disrupt and char, but while keeping its other physical characters yields to the electric pressure up to a point within the insulation, and absorbs energy as a brush discharge does. Unfortunately air is the only insulation which has been investigated under these conditions.

111. If this is so the consequence of using cables having a smaller dielectric thickness than corresponds to the curves is that energy is lost and capital economy made at the expense of the factor of safety against disruption. The way to reduce the energy loss to a minimum, and to nearly halve the cost of many high-tension cables, is to reduce the voltage gradient where it is too steep, by "grading" capacity conductivity and dielectric strength.

112. Curve 19 shows the economy effected by using a "graded" cable, although the price of insulation has been taken at *double* the price for the insulation of curve 17.

[1] The disruptive strength of vulcanised rubber found by T. Gray is 470. 100 is the disruptive strength of most oils.

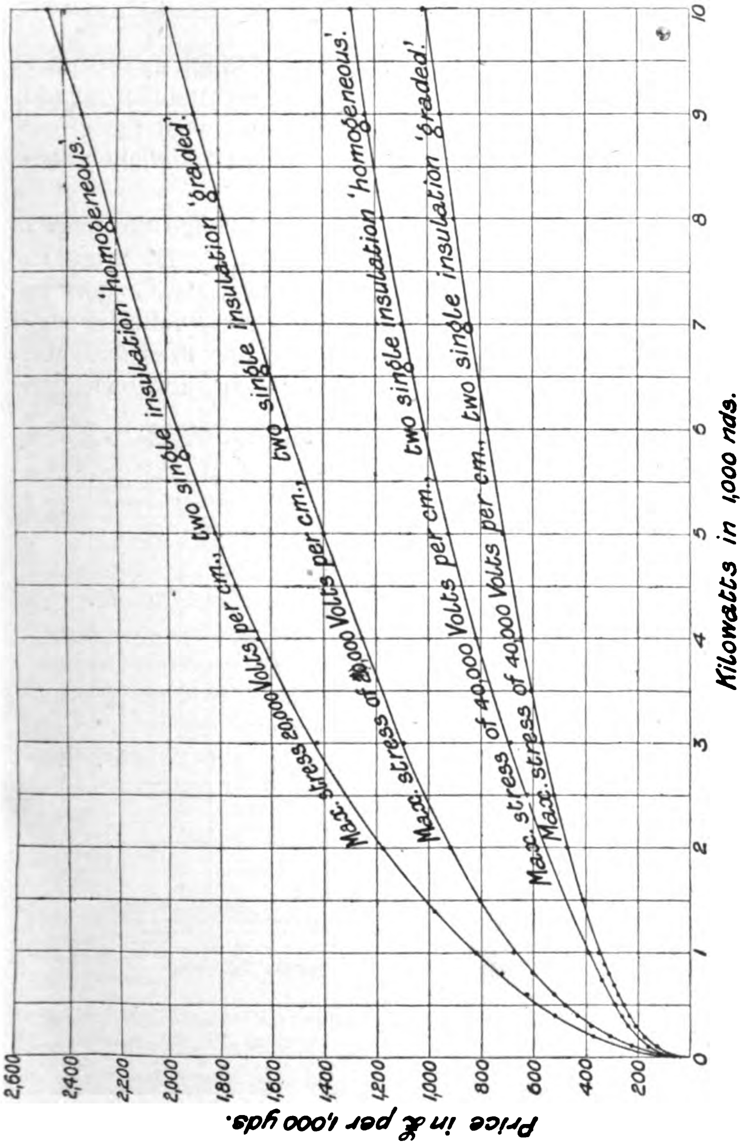

FIG. 21.—Curves showing the economy of (1) Increasing the disruptive strength; (2) grading the insulation. This figure is a summary of Figs. 17, 19, 20.

113. Fig. 20 shows the economy of doubling the strength of the insulation and should be compared with Fig. 17.

114. Fig. 20 also shows the greater economy of "grading" the insulation used.

Fig. 22 shows the unequal stresses to which an ordinary 37/14 high-tension cable may be put if no attention is paid to "grading." The horizontal line shows what the stress would be if the insulation were "graded" and the same voltage applied.

115. I wish, in conclusion, to acknowledge the help I have received from my assistants—Mr. C. B. Wigg in calculating cable prices, and other matters, Mr. Gregory in making diagrams, and Mr. Story for several valuable suggestions; as well as to Professor Perry, our President, Mr. Swinburne and Mr. Whitehead for help acknowledged within the paper.

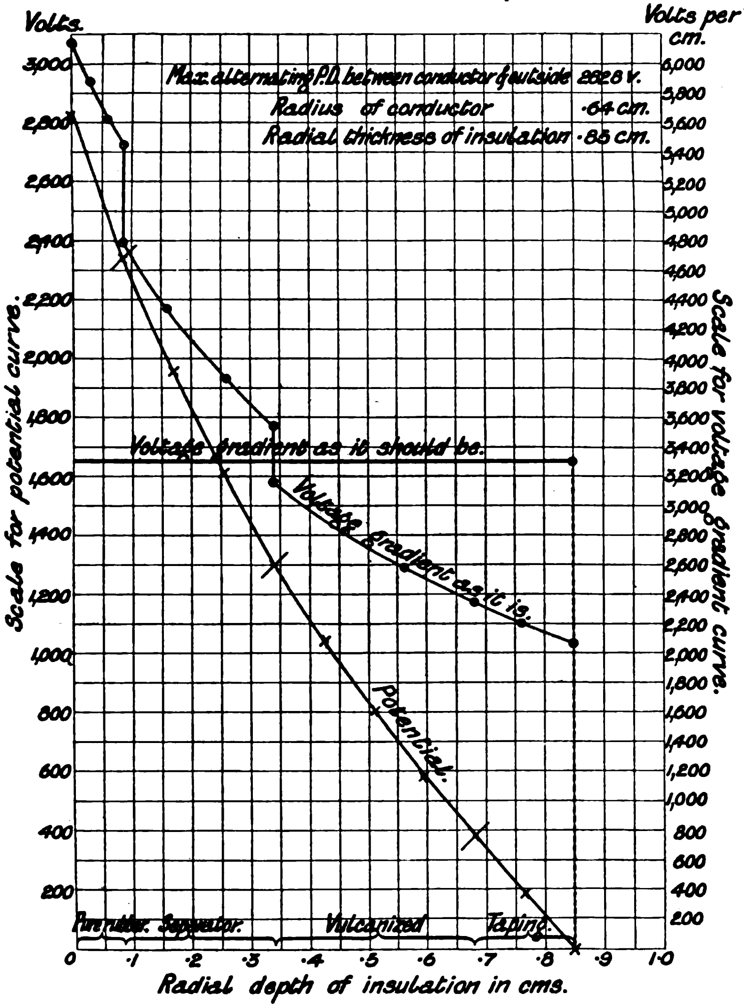

FIG. 22.—Curves showing the potential and rate of fall of potential through the insulation of a 37/14 cable made up as follows :—

Next to core	... ...	·085 CMS of pure rubber.
Then	... .	·255 CMS of separator.
Then	... .	·34 CMS vulcanised rubber.
And outside	... ...	·17 CMS of taping.

APPENDIX I.

Materials.	Price per Ton.	D.S. in Kilowatts per centimetre.		S.I.C. (air = 1).		I.R. in Megohms per cubic centimetre.		Authorities. D.S.	Authorities. S.I.C.	Authorities. I.R.	Viscosity at 0°C Water = ·01.
	£		°C		°C		°C				
Air	...	27·0	...	1	...	...	...	...	...	...	...
Amylene...	...	...	...	2·201	15-16·2	...	...	...	Landolt & Jahn	...	...
	...	...	...	2·201	15	...	...	...	A. L. Clark	...	...
	...	...	...	2·05		...	...	...	A. L. Clark	...	...
Arachide...	...	...	...	3·17	...	...	...	...	Hopkinson	...	...
Barytes (Lump Carbonates, 90 95)...	3·75	...	...	...	...	...	...	...	...	...	...
Benzene	...	...	...	2·198	...	...	...	...	Silow	...	·0064 at 20°C Wykander
Benzine (= Octane)	...	...	...	1·934	...	...	...	...	Landolt & Jahn	...	...
Benzol	7·50	...	...	2·38	...	...	...	...	A. L. Clark	...	...
Beryll (Nertscinsk)	...	...	...	$k_c = 7·85$ $k_a = 7·44$	...	...	...	...	H. Starke	...	...
Bitumen, Vulcanised	55	...	...	...	...	...	...	...	...	...	...
Calcspar (Iceland)	...	...	...	$k = 8·25$ $k = 8·54$	...	...	...	...	H. Starke	...	...
Callendar's Cable (Bitumen) ...	45	...	...	...	...	$0·45 \times 10^9$	15	...	...	...	...
Castor Oil	...	...	...	4·82	...	...	...	...	Hopkinson	...	...
	...	...	...	4·78	...	...	...	...	Hopkinson	...	...
Castor Oil, White	30·0	...	...	4·92	...	...	...	...	A. L. Clark	...	...
Chalk	...	...	...	6·14	...	...	...	...	Thwing	...	...
Colza	...	...	...	3·07 3·14	...	$1·0 \times 10^5$ $15·0 \times 10^5$	...	...	Hopkinson	W. Gray, '92	...
Cotton Seed Oil	...	67	...	3·88	...	50×10^5	...	T. Gray	A. L. Clark	W. Gray	...
Cotton with Rosin 6 and Rosin Oil 9	80	...	...	3·4	...	$7·3 \times 10^9$	...	Fowler Waring, Co.	F. W. Co.	...	...
Crude Oil, Nat. West Virginia (sp. gr. 0·29)	...	81	...	...	...	...	...	T. Gray (1 cm.)	...	...	...
CS_2	...	...	...	2·67	...	...	...	...	Hopkinson	...	...
Ebonite	...	...	...	3·15	...	...	...	...	Boltzman	...	...
Ether	...	...	...	4·75	...	...	...	...	Hopkinson	...	...
Export Distillate (? of Kerosene) ...	...	...	...	2·06	...	...	...	...	A. L. Clark	...	...
Fluor spar (Stolberg, Harz)	...	...	...	6·92 6·7	...	...	...	...	H. Starke Romich & Nowall	...	...
Glycerine	...	...	...	56·2	...	...	...	...	Thwing	...	·42·2 at 2·8°C; 4·94 at 26°C
Gutta Percha	...	109·5		4·2 3·59 Smith		7×10^9 $0·45 \times 10^9$ $0·025 \times 10^9$	0 24 24	Lombardi (2 mm.)	... ...	Latimer Clark F. Jenkin	... ...

Materials.	Price per Ton.	D.S. in Kilovolts per centimetre.		S.I.C. (air = 1).		I.R. in Megohms per cubic centimetre.		Authorities. D.S.	Authorities. S.I.C.	Authorities. I.R.	Viscosity at 0°C. Water = ·01.
	£		°C.		°C.		°C.				
Gypsum (Montmartre)	...	...	...	5·04 6·33	...	...	...	...	H. Starke Currie	...	...
High Gravity Oil (?)...	...	...	...	2·12	...	...	...	...	A. L. Clark	...	...
Hooper Composition	say 200	...	...	3·1	...	15×10^9	24	...	...	...	...
Ice—13·5°C.	...	...	...	22·168	...	...	...	...	Ayrton & P	...	...
—12·4°C.	...	...	...	...	...	2240	...	...	...	...	...
— 0·2°C.	...	...	...	...	...	284	...	...	...	...	...
Jute with Rosin 6 and Rosin Oil 9...	60	...	...	2·7	...	$11·9 \times 10^9$	15	...	...	...	...
Kerosene (ordinary), Nonane, etc., to Pentadecane	...	50	...	2·22	...	...	...	McFarlane & Pierce	A. L. Clark	...	0·02 at 22°C Bartolli
Kerosene, Water White (150°C.) ...	...	...	...	2·23	...	...	...	McFarlane & Pierce	A. L. Clark	...	...
Lard Oil	...	...	...	...	...	$2·2 \times 10^5$ $5·0 \times 10^5$	...	...	...	W. Gray, '92	...
Lemon Oil	...	...	...	2·25	...	...	...	...	Tomazewski	...	...
Linseed and Petroleum	...	21·0	...	2·4	...	...	...	Lombardi	Lombardi	...	...
Linseed Oil (boiled)	30·25	...	...	...	...	$0·75 \times 10^5$	...	Lombardi (2 mm.)	Hopkinson	W. Gray	...
,, ,, (raw)	29·25	105	...	3·37	...	$0·28 \times 10^5$	...				
Manilla Paper (unsized)	...	...	...	1·8	...	...	...	...	...	...	...
Mica	...	...	...	6·67	...	...	...	Lombardi	H. Starke	...	...
	...	400	...	6·64	...	$·084 \times 10^9$	...	...	Klemencic	...	...
	...	2 000	...	5·84	...	$0·084 \times 10^9$	20	T. Gray	H. Starke	Ayrton & Perry	...
	...	...	...	5·80	...	...	...	...	Starke	...	...
	...	...	...	6·02	...	$·084 \times 10^9$	...	...	H. Starke	...	...
Mica (Canada)	...	...	...	5·84	...	...	...	...	H. Starke	...	...
Mica (Finbo Bei Fahlun)	...	...	...	5·80	...	...	...	...	H. Starke	...	...
Neat's Foot Oil...	...	...	...	3·22	...	...	...	...	A. L. Clark	...	...
	...	...	...	3·07	...	...	...	...	Hopkinson	...	...
Nut Oil	28·5	...	...	...	...	$0·4 \times 10^5$ $1·0 \times 10^5$	...	...	...	W. Gray	...
Olive Oil...	...	82	...	3·08 3·52	...	very large electrification = 70%	...	McFarlane & Pierce	Aron & Rubens A. L. Clark	Lombardi	0·22 at 19°C Lamansky
	...	...	...	3·16	...	...	...	...	Hopkinson	W. Gray	3·26 at 0°C Reynolds
	...	...	...	3·52	...	...	...	...	A. L. Clark	...	...
Ozokerite	...	...	...	2·13	...	...	...	...	Hopkinson	...	...

Materials.	Price per Ton.	D.S. in Kilovolts per centimetre		S.I.C. (air = 1).		I.R. in Megohms per cubic centimetre.		Authorities.			Viscosity at 0°C. Water = ·01.
								D.S.	S.I.C.	I.R.	
	£		°C.		°C.		°C.				
Paper and Rosin Oil	...	...	...	2·4	...	3×10^9	15	...	...	...	...
Paper, Beeswaxed	...	540	...	...	...	...	...	McFarlane & Pierce	...	...	...
Paper, Paraffined	...	360	...	...	...	...	...	McFarlane & Pierce	...	...	...
Paper with Rosin 3 and Rosin Oil 9	...	...	...	2·75	...	$2·4 \times 10^9$	...	...	F. W. Co.	...	...
Paraffin Oil	...	105	...	2·71	...	„	...	Lombardi	A. L. Clark	...	...
Paraffin Oil (0·28 specific gravity) ...		91	...	...	...	...	...	T. Gray (1 cm.)	...	...	...
	...	105	...	2·1	...	34×10^9	46	Lombardi	Lombardi	Ayrton & Perry	...
		...	...	...	...	109×10^9	18	...	...	H. P. Gaze, '96	...
Paraffin Wax		275	...	2·32	...	24×10^9	...	Lombardi	Boltzman	Electrician, '92	...
	...	130	...	...	...	109×10^9	...	McFarlane & Pierce		H. P. Gaze, '96	...
Paraffin Wax (melted)	...	56	...	...	...	...	...	McFarlane & Pierce	...	...	...
Petroleum Oil (common)	...	105	...	2·10	...	109×10^9	...	...	Hopkinson	Electrician	0·019 at 17·5 Petroff
Petroleum Oil (Field's)	...	...	...	2·07	...	„	...	...	Hopkinson	...	...
Petroleum Spirit (Hexane)	...	...	...	1·922	13	...	...	...	Hopkinson	...	...
Pine Wood — Across the fibre (air dried) ...	...	...	...	...	...	$·009 \times 10^5$	...	...	Mazzotto	...	...
„ „ (stove dried)	...	...	...	...	...	$·8 \times 10^5$	...	...	Mazzotto	...	...
Along the fibre (air dried)	7·5 pulp	...	...	...	...	35·6	...	...	Mazzotto	...	...
„ „ (stove dried)	...	...	...	...	...	$·2 \times 10^5$	...	...	Mazzotto	...	...
Porcelain	...	...	...	4·38	...	...	...	...	Currie	...	...
Potash Alum	...	...	...	6·67	...	...	...	...	H. Starke	...	...
Quartz	...	...	...	$4·73\ k_c = k_a$	...	...	...	...	H. Starke	...	...
Quartz—1, along optic axis	...	...	...	4·55	...	...	...	...	Currie	...	...
„ 2, across „ „	...	...	...	4·9	...	...	...	...	Currie	...	...
Rape Oil...	...	...	...	2·2–3·0	...	$0·5 \times 10^5$ / $5·0 \times 10^5$	...	...	Smithsonian tables	W. Gray	1·63 at 20°C Meyer
Rock Salt (Stassfurt)	...	...	...	6·29	...	...	...	...	H. Starke	...	...
„	...	...	...	18·0	...	...	...	...	Hopkinson	...	...
Rosin				3·0	...	...	...		Lombardi	...	...
	...	139	...	2·55	...	...	...	Lombardi	Starke, Boltzman	...	...
				1·77	...	...	...		Lupton	...	...
Rosin Oil	6·5	270 / 1350	...	...	...	3200×10^5	18	Chattock	...	...	...
Rubber, Pure (Para)	400	...	...	2·34	...	$10·9 \times 10^9$	24	...	...	Electrician	...
Rubber, Siemen's special	say 200	...	...	...	...	$16·2 \times 10^9$	15	...	...	...	...

Materials.	Price per Ton.	D.S. in Kilovolts per centimetre.		S.I.C. (air = 1).		I.R. in Megohms per cubic centimetre.		Authorities.			Viscosity at 0°C. Water = ·01.
								D.S.	S.I.C.	I.R.	
	£		°C.		°C.		°C.				
Rubber, Vulcanised	say 200	476	...	2·94	...	$1·5 \times 10^9$	15	T. Gray	Schiller	Electrician	...
Selenium	...	...	...	10·2	...	...	...	...	Romich & Nowall	...	...
Sesame	...	...	...	3·17	...	...	...	...	Hopkinson	...	...
Shellac	...	...	...	2·95–3·73	...	9×10^9	28	...	Wullner	...	...
Spermaceti	...	112	...	2·18 1·3–1·6	... ...	... ...	... ...	... ...	Rosetti Faraday	... ...	... ...
Sperm Oil	...	...	...	3·02	...	...	...	...	Hopkinson	...	·08–·07 at 19°C Lamansky
Stearine	...	9·2	...	2·4	...	...	...	Lombardi	...	...	...
Sulphur	... ...	... ...	... ...	3·84 3·34–4·14 2·88–3·21	... ...	... ...	... ...	... ...	H. Starke H. Starke Wullner	... ...	... ...
"Sweet Neutral Oil"	...	...	...	2·36	...	...	...	...	A. L. Clark	...	...
Sylvine	...	...	...	4·94	...	...	...	...	H. Starke	...	...
Tar	...	...	...	1·8	...	...	...	...	...	...	...
Tolmene	...	...	...	2·2–2·4	...	...	...	...	Smithsonian tables	...	·0059 at 20°C. Landolt
Turpentine (commercial)	29·25	94	...	2·23	...	...	...	McFarlane & Pierce	Hopkinson	...	...
Vaseline	...	91	...	2·17	...	...	...	T. Gray (1 cm.)	Fuchs	...	...
Water, Distilled	...	1050	...	78·5	...	72×10^6 $3·4 \times 10^5$ $91·0 \times 10^5$ 1188×10^5	20 11 4 0·7	Chattock	Thwing	Chattock Ayrton & P. Ayrton & P. Ayrton & P.	·0100 at 20°C Poissenille ... ... ·0178 at 0° Crookes
White Lead (dry)	20	...	...	...	...	...	...	...	...	...	...
Xylene	...	...	...	2·3–2·6	...	...	...	...	Smithsonian tables	...	...
Xylol	...	...	...	2·34	...	...	...	...	A. L. Clark	...	...
Yellow Wax	...	...	...	1·86	...	...	...	...	...	...	...

APPENDIX II.

T. Gray (*Amer. Assoc.*, 48. pp. 122–123, 1899), strength in kilovolts per cm.

Vaseline Oil ...	131	120	109	103	105	95	96	91	...	...
Paraffin, 0·28 sp. gr.	91	81	76	71	73	70	69	70	...	...
Paraffin, 0·26 sp. gr.	101	89	85	79	79	71	66	64	62	60
Natural W. Virginia Crude Oil, 29 sp. gr.	81	79	74	72	69	62	63	62	...	...
Thickness ...	1 cm.	2 cm.	3 cm.	4 cm.	5 cm.	6 cm.	7 cm.	8 cm.	9 cm.	10cm

APPENDIX III.

FREQUENCY AND DIAMETERS OF COPPER TABULATED BY MR. MORDEY FROM LORD KELVIN'S FORMULA.

This formula probably deals with solid copper and not strands, which have sometimes 50 per cent. more surface and 30 per cent. more area than the equivalent rod. For example, the circumference of a 37-strand cable is to the circumference of a circular rod of equivalent conductivity as 12·22 : 8·27.

How far this affects the impedance, or how the impedance is diminished by the slight insulation which unavoidably exists between the strands of certain classes of cable, is a matter which can probably be most easily settled by experiments which have possibly been made, though I think not published. The same applies to the effect on impedance of the bulkiness of aluminium. It would be arduous to settle this matter from Lord Rayleigh's formula.

Diam. Copper.[1]		See area.		Increase over ordinary res. less than per cent.	Current at 450 to sq. in.	Watts lost at 2000 volts.	Watts lost at 100 volts.	Frequency per sec.
mm.	inch.		sq. in.	per cent.				
10	·3937	78·54	·12	$\frac{1}{100}$	55	111,000	5,500	80
15	·590	167·7	·274	$2\frac{1}{2}$	133	266,000	13,300	,,
20	·787	314·16	·487	8	220	440,000	22,000	,,
25	·984	490·8	·760	$17\frac{1}{2}$	,,	...	...	,,
40	1·575	1265·0	1·95	68	,,	...	...	,,
100	3·937	7854·0	12·17	3·8 times	,,	...	...	,,
1000	39·37	78540·0	12·17	35 times	,	...	...	,,
9	·3543	63·62	·098	per cent. $\frac{1}{100}$	45	90,000	4,500	100
13·4	·5280	141·3	·218	$2\frac{1}{2}$	98·5	197,000	9,850	,,
18·0	·7086	254·4	·394	8	178	356,000	17,800	,,
22·4	·8826	394·0	·611	$17\frac{1}{2}$	,,	..	...	,,
7·75	·3013	47·2	·071	$\frac{1}{100}$	32	64,000	3,200	133
11·61	·4570	106	·164	$2\frac{1}{2}$	74	148,000	7,400	,,
15·5	·6102	189	·292	8	131·4	263,000	13,140	,,
15·5	·7622	294	·456	$17\frac{1}{2}$	...	..	...	,,

[1] From *Science Abstracts*, Russell's E. L. Cable, 1892, p. 5.

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T. GRAY (*Amer. Assoc.*, 48. pp. 122–123, 1899), strength in kilovolts per cm.

Vaseline Oil ...	131	120	109	103	105	95	96	91	...	...
Paraffin, 0·28 sp. gr.	91	81	76	71	73	70	69	70	...	...
Paraffin, 0·26 sp. gr.	101	89	85	79	79	71	66	64	62	60
Natural W. Virginia Crude Oil, 29 sp. gr.	81	79	74	72	69	62	63	62	...	...
Thickness ...	1 cm.	2 cm.	3 cm.	4 cm.	5 cm.	6 cm.	7 cm.	8 cm.	9 cm.	10 cm

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How far this affects the impedance, or how the impedance is diminished by the slight insulation which unavoidably exists between the strands of certain classes of cable, is a matter which can probably be most easily settled by experiments which have possibly been made, though I think not published. The same applies to the effect on impedance of the bulkiness of aluminium. It would be arduous to settle this matter from Lord Rayleigh's formula.

Diam. Copper.[1]		Sce area.		Increase over ordinary res. less than per cent.	Current at 450 to sq. in.	Watts lost at 2000 volts.	Watts lost at 100 volts.	Frequency per sec. ∿
mm.	inch.		sq. in.	per cent.				∿
10	·3937	78·54	·12	$\frac{1}{100}$	55	111,000	5,500	80
15	·590	167·7	·274	$2\frac{1}{2}$	133	266,000	13,300	,,
20	·787	314·16	·487	8	220	440,000	22,000	,,
25	·984	490·8	·760	$17\frac{1}{2}$	,,	...	...	,,
40	1·575	1265·0	1·95	68	,,	...	...	,,
100	3·937	7854·0	12·17	3·8 times	,,	...	...	,,
1000	39·37	78540·0	12·17	35 times	,	...	...	,,
9	·3543	63·62	·098	per cent. $\frac{1}{100}$	45	90,000	4,500	100
13·4	·5280	141·3	·218	$2\frac{1}{2}$	98·5	197,000	9,850	,,
18·0	·7086	254·4	·394	8	178	356,000	17,800	,,
22·4	·8826	394·0	·611	$17\frac{1}{2}$	,,	..	...	,,
7·75	·3013	47·2	·071	$\frac{1}{100}$	32	64,000	3,200	133
11·61	·4570	106	·164	$2\frac{1}{2}$	74	148,000	7,400	,,
15·5	·6102	189	·292	8	131·4	263,000	13,140	,,
15·5	·7622	294	·456	$17\frac{1}{2}$	...	..	...	,,

[1] From *Science Abstracts*, Russell's E. L. Cable, 1892, p. 5.

APPENDIX IV.

Capacity of Cables Before and After making a Three-Core Cable Rubber-Covered. Each Strand was immersed in Water.

Date of Test.	No. of Strands.	Sectional Area. m/m 2.	Ins. resis. at 15°C. after 1 minute.	2 minutes.	3 minutes.	4 minutes.	Capacity in mfds. per kilometre.	Copper resis. per kilometre.	Remarks.
1/7/98	1	35	4672	5850	6680	7735	0·477	0·475	after 36 hrs. in water.

Tested for 30 minutes with 20,000 volts between conductor and earth, and re-tested as below.

1/7/98	1	35	4672	5850	6680	7735	...	...	
1/7/98	2	35	3815	5850	6685	7630	0·434	0·494	after 36 hrs. in water.

Tested for 30 minutes with 20,000 volts between conductor and earth, and re-tested as below.

1/7/98	2	35	3815	5850	6685	7630	...	...	
	3	35	4670	7752	9300	9982	0·427	0·497	after 36 hrs. in water.
	3	35	4670	7752	9300	9982	...	...	after 20,000 v. for ½ an hour.

The three were then stranded together and armoured and re-tested as follows:

14/7/98	1	35	4380	7320	10,800	...	0·492	0·495	
	2	35	4380	7320	10,800	...	0·492	0·494	
	3	35	4080	7320	10,100	...	0·392	0·497	

Tested for ½ an hour at 20,000 volts, and all tests were identical.

Cable No. 2, made of "Kableit."

2/7/98	1	35	1292	1840	2450	2760	0·376	0·497	after 8 days in water.

Every test identical after 20,000 volts for ½ an hour.

4/7/98	2	35	1303	1843	2220	2460	0·390	0·496	after 8 days in water.

Every test the same after 20,000 volts for ½ an hour.

4/7/98	3	35	1180	1685	2022	2240	0·359	0·496	after 8 days in water.

Every test the same again after 20,000 volts for ½ an hour.

The three cables were then stranded and armoured over all.

14/7/98	1	35	1282	2120	3040	...	0·354	0·497
	2	35	1390	2330	3520	...	0·354	0·496
	3	35	1318	2330	3040	...	0·359	0·486

Tested for ½ an hour at 20,000 volts between conductors, and re-tested. Everything the same.

It is interesting to note that the capacity per kilometre of each strand of the stranded three-wire cable is not more than 10 per cent. above the capacity of that strand separately before assembling the rubber-covered cores.

Where each core is lead-covered as in case 2, the capacity goes down a little, possibly due to stretch of the copper in armouring, or simply a temperature error.

The above figures are taken from a paper in the *India Rubber World*, December 1st, 1899, by O. Schaefer (Manager of Duisburg Cable Works, *a* / R). He considers that there is practically no danger to cables, when forming part of an overhead transmission, from lightning, even when there are only lightning arresters at the switchboards.

The above tests were made on 300 yards of two cables 1, and 2, designed for 10,000 volts.

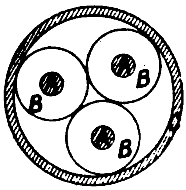

FIG. 23. Cable (2).
Not to scale.

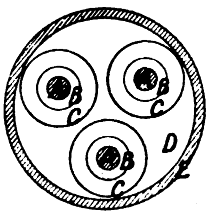

FIG. 24. Cable (1).
Not to scale.

CABLE (1).

B = Each insulated with vulcanised rubber 0·2 inch.
C = Lead-covered and armoured.
A = 35 sq. mm., copper tinned.

CABLE (2). Coppers each, untinned 35 sq. mm., section. Insulated with "Kableit" thickness about 0·2 inch, then ozokerited and each of the three wires lead-covered separately. The material is claimed to be non-hydroscopic.

A = Copper 35 sq. mm.
B = Insulation 0·2 inch thick.
C = Lead.
E = Armoured overall.
D = Jute worming.

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Tested for 30 minutes with 20,000 volts between conductor and earth, and re-tested as below.

1/7/98	1	35	4672	5850	6680	7735	...	...	
1/7/98	2	35	3815	5850	6685	7630	0·434	0·494	after 36 hrs. in water.

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	2	35	4380	7320	10,800	...	0·492	0·494	
	3	35	4080	7320	10,100	...	0·392	0·497	

Tested for ½ an hour at 20,000 volts, and all tests were identical.

Cable No. 2, made of "Kableit."

2/7/98	1	35	1292	1840	2450	2760	0·376	0·497	after 8 days in water.

Every test identical after 20,000 volts for ½ an hour.

4/7/98	2	35	1303	1843	2220	2460	0·390	0·496	after 8 days in water.

Every test the same after 20,000 volts for ½ an hour.

4/7/98	3	35	1180	1685	2022	2240	0·359	0·496	after 8 days in water.

Every test the same again after 20,000 volts for ½ an hour.

The three cables were then stranded and armoured over all.

14/7/98	1	35	1282	2120	3040	...	0·354	0·497	
	2	35	1390	2330	3520	...	0·354	0·496	
	3	35	1318	2330	3040	...	0·359	0·486	

Tested for ½ an hour at 20,000 volts between conductors, and re-tested. Everything the same.

It is interesting to note that the capacity per kilometre of each strand of the stranded three-wire cable is not more than 10 per cent. above the capacity of that strand separately before assembling the rubber-covered cores.

Where each core is lead-covered as in case 2, the capacity goes down a little, possibly due to stretch of the copper in armouring, or simply a temperature error.

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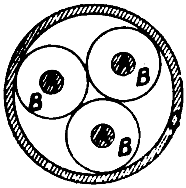
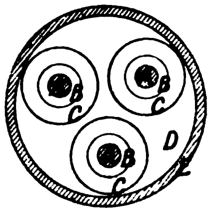


FIG. 23. Cable (2).
Not to scale.



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A = Copper 35 sq. mm.
B = Insulation 0·2 inch thick.
C = Lead.
E = Armoured overall.
D = Jute worming.

APPENDIX IV.

CAPACITY OF CABLES BEFORE AND AFTER MAKING A THREE-CORE CABLE RUBBER-COVERED. EACH STRAND WAS IMMERSED IN WATER.

Date of Test.	No. of Strands.	Sectional Area. m/m 2.	Ins. resis. at 15°C. after 1 minute.	2 minutes.	3 minutes.	4 minutes.	Capacity in mfds. per kilometre.	Copper resis. per kilometre.	Remarks.
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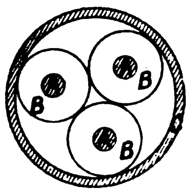
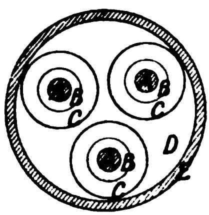


FIG. 23. Cable (2).
Not to scale.



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A = Copper 35 sq. mm.
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C = Lead.
E = Armoured overall.
D = Jute worming.

APPENDIX V.

In the appended tables, the various systems are compared on the common basis, that the voltage between no two conductors exceeds 14,140 maximum. The strain therefore on the insulation of the generators or transformers is the same in all cases.

The systems are as follows :—

A. Direct current with one concentric cable, the outer being earthed. Working pressure between conductors, 14,140 volts. (It *might* be cheaper to use two single cables and earth a middle *point* as in Mr. Swinburne's case 1 ; but this has not been worked out, and is not very usual in practice, except on the three-wire system, which is not considered.

B. Single-phase alternating current. Working pressure, 10,000 volts, otherwise same as A.

C. Biphase with two concentric cables ; *neither outer is earthed,* but a middle point in the machine, as shown at J in S. P. Thompson's book on "Polyphase Electric Currents," at figures 50 and 51, is earthed working pressure 10,000 volts on each phase.

D. Biphase with two concentric cables, the outers of both being earthed, these outers being the common return. Working pressure, 7,070 volts on each phase.

E. Triphase with three single conductors, none of them earthed, but the common junction of the star winding is supposed to be earthed. Working pressure, 10,000 volts on each phase.

F. Triphase with two concentrics, the outers being earthed, the two outers together forming the third conductor which is equally divided between the two concentrics. Working pressure, 10,000 volts on each phase.

Max. allowable slope of volts = S = 20,000 volts per cm.
5,000 K.W. put into cable; loss of 10 per cent. in 20 miles.

I.

System.	Amperes per wire.	Max. volts for R.	Eff. volts. $= e$.	Eff. amps. $= i$.	Power formula.	K.W. delivered.	Cost per 1000 yards.	K.W. per £1.	Comparative costs.
							£		
A. Direct-current	354	14,140	14,140	354	ei	4,500	675	6·67	1
B. Single-phase	500	14,140	10,000	500	ei	4,500	1,201	3·75	1·77
C. Biphase	250	14,140	10,000	250	$2\,ei$	4,500	1,444	3·12	2·14
D. Biphase	354, 354, 500	10,000	7,070	354	$2\,ei$	4,500	1,687	2·67	2·5
E. Triphase	288	8,180	10,000	166	$3\,ei$	4,500	970	4·64	1·43
F. Triphase	288	14,140	10,000	166	$3\,ei$	4,500	1,111	4·05	1·64

N.B.—In all cases when two or more cables are required, the cost of all the cables required is included in the above prices.

S = 20,000 volts per cm.
5,000 K.W. put into cable; 10 per cent. loss in 47 miles.

II.

System.	Amperes per wire.	Max. volts. for R.	Eff. volts. $= e$.	Eff. amps. $= i$.	Power formula.	K.W. delivered.	Cost per 1000 yards.	K.W. per £1.	Comparative costs.
							£		
A. Direct-current	354	14,140	14,140	354	ei	4,500	1,370	3·28	1
B. Single-phase	500	14,140	10,000	500	ei	4,500	2,520	1·77	1·84
C. Biphase	250	14,140	10,000	250	$2\,ei$	4,500	2,940	1·53	2·15
D. Biphase	354, 354, 500	10,000	7,070	354	$2\,ei$	4,500	3,630	1·24	2·65
E. Triphase	288	8,180	10,000	166	$3\,ei$	4,500	2,010	2·24	1·46
F. Triphase	288	14,140	10,000	166	$3\,ei$	4,500	2,131	2·11	1·55

S = 20,000 volts per cm.

2,500 K.W. put into cable; loss of 10 per cent. in 20 miles.

III.

System.	Amperes per wire.	Max. volts for R.	Eff. volts $= e$.	Eff. amps. $= i$.	Power formula.	K.W.	Cost per 1,000 yards.	K.W. per £1	Comparative costs.
							£		
A. Direct-current	177	14,140	14,141	177	ci	2,250	429	5·24	1
B. Single-phase	250	14,140	10,000	250	ci	2,250	670	3·36	1·56
C. Biphase	125	14,140	10,000	125	$2\,ci$	2,250	1,060	2·11	2·48
D. Biphase	177, 177, 250	10,000	7,070	177	$2\,ci$	2,250	1,010	2·23	2·35
E. Triphase	144	8,110	10,000	83	$3\,ci$	2,250	579	3·88	1·35
F. Triphase	144	14,140	10,000	83	$3\,ci$	2,250	741	3·04	1·72

S = 20,000 volts per cm.

2,500 K.W. put into cable; loss of 10 per cent. in 47 miles.

IV.

System.	Amperes per wire.	Max. volts for R.	Eff. volts $= e$.	Eff. amp. $= i$.	Power formula.	K.W.	Cost per 1000 yards.	K.W. per £1.	Comparative costs.
							£		
A. Direct-current	177	14,140	14,140	177	ci	2,250	764	2·95	1
B. Single-phase	250	14,140	10,000	250	ci	2,250	1,370	1·64	1·79
C. Biphase	125	14,140	10,000	125	$2\,ci$	2,250	1,745	1·29	2·28
D. Biphase	177, 177, 250	10,000	7,070	177	$2\,ci$	2,250	1,939	1·16	2·54
E. Triphase	144	8,180	10,000	83	$3\,ci$	2,250	1,049	2·14	1·36
F. Triphase	144	14,140	10,000	83	$3\,ci$	2,250	1,240	1·82	1·62

APPENDIX VI.

LET the electrodes be sufficiently large plates so that the electric field between them may be considered uniform.

Let E = potential difference between the plates when the dielectric between them ruptures.

l = distances between the plates at this moment.

S = dielectric strength.

If Maxwell's assumption be correct, we ought to have—

$$S = \frac{E}{l};$$

that is, considering S a constant of the substance, the curve connecting E and l ought to be a straight line through the origin. We see that air, empire cloth, and Fuller board give fairly good straight lines for the E and l curves. Mica is a fairly straight line, *but none of them pass through the origin.*

The curve being a straight line *not* passing through the origin indicates that the relation between E and l is of the form of—

$$E = \alpha + \beta l,$$

where α and β are constants, different of course for different dielectrics. If instead of plotting E and l we plot E/l and l and put $E/l = F$, F is called the electric intensity, and we have—

$$F l = \alpha + \beta l.$$

That is, the curve connecting F and l should be a rectangular hyperbola. Mica and empire cloth are very fair approximations (also air). Now all the curves show that α is small, therefore writing the equation between F and l in the form—

$$F = \frac{\alpha}{l} + \beta,$$

we see that when l is large compared with α we get $F = \beta =$ constant; that is, the dielectric strength may be measured by the electric intensity as before assumed, and we confirm the formula—

$$E = S r \log \frac{R}{r}.$$

From the curves we may conjecture that after a thickness of, ¼ in. or somewhat less perhaps, the dielectric strength curve would be sensibly parallel to the axis of thickness, and may be dealt with as a constant, and I have considered it so throughout. I am indebted to Mr. Whitehead for this simple way of considering the case, and for much assistance in other matters where it seemed advisable to consult Maxwell.

The fact that the disruptive stress is measured by the voltage gradient is most important. I do not know of any experimental basis for supposing that the disruptive stress should be measured by the energy per unit volume in the insulator. If this were so, the capacity per unit length of cable being—

$$= \frac{k}{2 \log_e \frac{R}{r}}$$

the resultant electric force—

$$=\frac{E}{r\ \mathrm{og}\frac{R}{r}}$$

and the stress S being measured by the energy is measured by—

$$S=\frac{K}{4}\frac{E^2}{\log\frac{R}{r}}$$

which is notably different from the formula in the text No. 12.

Whereas, on the contrary, Lord Kelvin's opinion (Paper on 'Electrostatics and Magnetism," Macmillan, London, 1872, p. 258), quoted by J. Trowbridge in *Phil. Mag.* (45, p. 98, 1898), is there experimentally confirmed, for air at constant temperature and volume, and he concludes, "when lengths of spark are plotted as abscissæ, and the corresponding electromotive forces as ordinates, the *curve is a straight line.*"

APPENDIX VII.

Extract translation. G. Mie. "Poynting's Theorem," *Zeitschr. Phys. Chem.* 34, pp. 522-528, Sept. 7, 1900.

"Take the case of two parallel equal very long wires. Call the thickness of the wire $2a$; the distance of the axes of the wires $2a$, the two wires are stuck in an infinite insulating medium and the ends of the system in one direction are at potential zero, so that at symmetrical points on the two wires the potentials of the wires are equal and opposite. Call the resistance of a wire per unit length w, the current strength J. The middle line between the two wires is taken for axis of z, the line joining the two opposite points of the axes of the wires is the axis of y, the line at right angles to it the axis of x. z_0 is the z co-ordinate of the end of the conductor where also both wires are at zero potential. Also for shortness let :—

$$b=\sqrt{a^2-a^2}\text{ and }C=\frac{p}{\log\left(\frac{a+b}{a-b}\right)}$$

Where $p=wJ$, the fall of potential along the length of the wire, then the electric potential V in the neighbourhood of a point (x, y, z) is :—

$$V=C\,(z_0-z)\qquad\log\frac{x^2+(y+b)^2}{x^2+(y-b)^2}."$$

[2] Maxwell, Vol. 1, Art. 55 and 68.

"Art. 68. Definition. The resultant electric intensity at any point is the force which would exist on a small body charged with the unit of positive electricity if it were placed there without disturbing the actual distribution of electricity. . . . Hence the quantity R is also called the electromotive intensity at the point (x y z)." (R stands for resultant electric intensity.)

"Art. 55. If the electromotive intensity at any point of a dielectric is gradually increased, a limit is at length reached at which there is a sudden electrical discharge through the dielectric. . . . The electromotive intensity when this takes place is a measure of what we may call the electric strength of the dielectric."

To utilise this formula of Mie's, let

V^1 = potential of the surface of one wire.

V^1 = " " " of the other wire.

$2V^1$ = difference of potential, = the maximum working voltage.

$$V = \frac{V^1}{\log \frac{a+b}{a-b}} \phi (xy)$$

When $\phi\ (xy) = \log \frac{x^2 + (y+b)^2}{x^2 + (y-b)^2}$

but we are concerned only with the maximum slope of the voltage which evidently occurs along the shortest distance between the two conductors, namely, along the line $x = 0$

$$\therefore V = \frac{V^1}{\log \frac{a+b}{a-b}} \phi (0, y); \text{ put } \frac{V^1}{\log \frac{a+b}{a-b}} = \text{to M as it is known.}$$

$$\text{then } V = M \log \left(\frac{y+b}{y-b}\right)^2$$

$$V = 2M \log \frac{y+b}{y-b}; \text{ put } \frac{y+b}{y-b} = H$$

$$(y + C) = H\ (y - C)$$

$$\therefore y = \frac{(H+1)^6}{(H-1)}$$

Again, to find the co-ordinate of the centres of the circles of equipotential:

$$V = C\ (z_0 - z) \log \frac{x^2 + (y^1 + b)^2}{x^2 + (y - b)^2}$$

$$\text{put } \frac{V}{C\ (z_0 - z)} = \log \xi$$

$$x^2 + (y + b)^2 = \xi \left\{ x^2 + (y - b)^2 \right\}$$

$$\text{put } \frac{\xi + 1}{\xi - 1} = \eta$$

$$(x^2 + y^2 + b^2)\ (\xi - 1) = 2\, b\, y\ (\xi + 1)$$

$$(x^2 + y^2 - 2\, b\, \eta\, y = -\, b^2$$

$$(x^2 + (y - b\, \eta)^2 = b^2\ (\eta^2 - 1)$$

$\therefore$ co-ordinates of centre are $x = 0$ $y = b\, \eta$

radius $= b \sqrt{\eta^2 - 1}.$

Appendix VIII., added April 29th, 1901. I am indebted to Mr. E. G. Cruise for the following table of prices of armoured 3-core cable.

APPENDIX VIII.

PRICES OF TRIPHASE LEAD-COVERED ARMOURED CABLES.

(GO AND RETURN.)

R.M.S. Voltage between Conductors.	Section of each Conductor in sq. in.	Diameter of Conductor. Inches.	Resis. per mile of each Conductor at 15° C. Ohms.	Diameter of Cable. Inches.	Approx. Weight of Cable per mile. Tons.	1,000 Amperes per sq. in. Normal Current per Conductor at 1,000 Amp. per sq. in.	1,000 Amperes per sq. in. Killowatts transmitted by the Cable.	1,000 Amperes per sq. in. Power-factor=1, C^2R Loss=5% Max. Distance Miles.	1,000 Amperes per sq. in. Power-factor=8, C^2R Loss=5% Max. Distance Miles.	1,000 Amperes per sq. in. Power-factor=1, C^2R Loss=7% Max. Distance Miles.	1,000 Amperes per sq. in. Power-factor=8, C^2R Loss=7% Max. Distance Miles.	800 Amperes sq. in. Normal Current per Conductor at 800 Amps. per sq. in.	800 Amperes sq. in. Killowatts transmitted by the Cable.	800 Amperes sq. in. Power-factor=1, C^2R Loss 5% Max. Distance Miles.	800 Amperes sq. in. Power-factor=8, C^2R Loss 5% Max. Distance Miles.	800 Amperes sq. in. Power-factor=1, C^2R Loss 7% Max. Distance Miles.	800 Amperes sq. in. Power-factor=8, C^2R Loss 7% Max. Distance Miles.	Approx. price of Cable per mile *d d* London.	Approx. Price per Yard.	£ Price of Cable per K.W. mile. Aver. between 1,000A sq. in. & 800 sq. in.
																		£	s. d.	
7,000	·0075	·12	5·6	1·48	8·8	7·5	90	4·8	3·2	6·7	4·48	6	73	6	3·8	8·4	5·32	310	3 6	3·8
"	·015	·16	2·8	1·6	10·4	15·0	180	4·8	"	"	"	12	145	"	"	"	"	406	4 7	2·5
"	·013	·204	1·4	1·72	12·0	30·0	360	"	"	"	"	24	290	"	"	"	"	506	5 9	1·55
"	·045	·248	0·93	1·84	13·6	45·0	540	"	"	"	"	36	435	"	"	"	"	604	6 10	1·24
"	·06	·29	0·7	1·96	15·2	60·0	720	"	"	"	"	48	580	"	"	"	"	658	7 6	1·01
"	·075	·336	0·56	2·08	16·8	75·0	900	"	"	"	"	60	725	"	"	"	"	800	9 0	·98
"	·09	·38	0·47	2·2	18·4	90·0	1,080	"	"	"	"	72	870	"	"	"	"	900	10 3	·92
"	·105	·42	0·4	2·32	20·0	105	1,271	"	"	"	"	81	980	"	"	"	"	1,000	11 4	·89
"	·12	·47	0·35	2·48	21·6	120	1,440	"	"	"	"	96	1,160	"	"	"	"	1,099	12 6	·84
"	·135	·51	0·3	2·64	23·2	135	1,634	"	"	"	"	108	1,305	"	"	"	"	1,200	13 7	·82
"	·15	·55	0·27	2·76	24·8	150	1,800	"	"	"	"	120	1,450	"	"	"	"	1,200	13 7	·80
"	·165	·59	0·24	2·82	26·16	165	1,998	"	"	"	"	132	1,597	"	"	"	"	1,380	15 8	·77
"	·18	·62	0·22	2·88	27·5	180	2,160	"	"	"	"	144	1,740	"	"	"	"	1,465	16 7	·75
"	·195	·65	0·2	2·94	28·9	195	2,361	"	"	"	"	156	1,887	"	"	"	"	1,550	17 7	·73
"	·21	·68	0·19	3·00	30·24	210	2,542	"	"	"	"	168	2,033	"	"	"	"	1,633	18 7	·71
"	·225	·72	0·18	3·06	31·7	225	2,700	"	"	"	"	180	2,173	"	"	"	"	1,717	19 6	·70

„	.24	.73	0.174	3.12	32.9	240	2,880	„	„	„	„	192	2,323	„	„	„	„	1,800	20 5	.69
„	.255	.75	0.163	3.18	34.3	255	3,088	„	„	„	„	204	2,468	„	„	„	„	1,880	21 4	.68
„	.27	.77	0.155	3.24	35.7	270	3,268	„	„	„	„	216	2,610	„	„	„	„	1,970	22 5	.67
„	.285	.784	0.146	3.30	37.0	285	3,451	„	„	„	„	230	2,783	„	„	„	„	2,053	23 4	.66
,	.3	.8	0.14	3.36	38.4	300	3,600	„	„	„	„	240	2,900	„	„	„	„	2,140	24 3	.65
10,000	.0075	.12	5.6	2.1	13.44	7.5	129	7.0	4.4	9.8	6.16	6	104	8.5	5.5	11.7	7.7	500		4.3
„	.015	.16	2.8	2.15	14.4	15.0	258	„	„	„	„	12	207	„	„	„	„	546		2.35
„	.03	.204	1.4	2.25	16.32	30.0	516	„	„	„	„	24	415	„	„	„	„	640		1.49
„	.045	.248	0.93	2.35	18.24	45.0	774	„	„	„	„	36	621	„	„	„	„	731		1.05
„	.06	.292	0.7	2.45	20.16	60.0	1,032	„	„	„	„	48	830	„	„	„	„	825		.88
„	.075	.336	0.56	2.55	22.08	75.0	1,290	„	„	„	„	60	1,035	„	„	„	„	918		.78
„	.09	.38	0.47	2.65	24.0	90.0	1,548	„	„	„	„	72	1,245	„	„	„	„	1,010		.72
„	.105	.424	0.4	2.75	25.92	105	1,817	„	„	„	„	81	1,401	„	„	„	„	1,100		.7
„	.12	.468	0.35	2.85	27.84	120	2,064	„	„	„	„	96	1,660	„	„	„	„	1,200		.66
„	.135	.512	0.3	2.95	29.76	135	2,336	„	„	„	„	108	1,868	„	„	„	„	1,290		.61
„	.15	.536	0.27	3.05	31.68	150	2,580	„	„	„	„	120	2,070	„	„	„	„	1,380		.59
„	.165	.592	0.24	3.1	32.8	165	2,857	„	„	„	„	132	2,283	„	„	„	„	1,500		.58
„	.18	.624	0.22	3.16	33.92	180	3,096	„	„	„	„	144	2,490	„	„	„	„	1,600		.57
„	.195	.656	0.2	3.22	35.04	195	3,376	„	„	„	„	156	2,698	„	„	„	„	1,700		.56
„	.21	.688	0.19	3.27	36.16	210	3,634	„	„	„	„	168	2,906	„	„	„	„	1,800		.55
„	.225	.720	0.18	3.33	37.28	225	3,870	„	„	„	„	180	3,105	„	„	„	„	1,900		.54
15,000	.0075	.114	5.6	2.74	18.24	7.5	194	10	6.6	14	9.24		155	13	8.2	18.2	11.48	660		3.8
„	.015	.144	2.8	2.80	19.8	15.0	388	„	„	„	„	12	310	„	„	„	„	730		2.68
„	.022	.174	1.85	2.86	21.4	22.0	572	„	„	„	„	17.6	456	„	„	„	„	800		1.55
„	.03	.204	1.4	2.92	23.04	30.0	776	„	„	„	„	24.0	620	„	„	„	„	860		1.23
„	.037	.234	1.11	2.98	24.6	37.0	960	„	„	„	„	29.6	766	„	„	„	„	927		1.07
„	.045	.264	0.93	3.04	26.2	45.0	1,164	„	„	„	„	36.0	932	„	„	„	„	993		.95
„	.052	.294	0.806	3.1	27.8	52.0	1,350	„	„	„	„	41.6	1,077	„	„	„	„	1,059		.87
„	.06	.324	0.7	3.16	29.4	60.0	1,552	„	„	„	„	48.0	1,240	„	„	„	„	1,127		.80
„	.067	.354	0.61	3.22	31.04	67.0	1,738	„	„	„	„	53.6	1,388	„	„	„	„	1,192		.76
„	.075	.384	0.56	3.28	32.04	75.0	1,940	„	„	„	„	60.0	1,550	„	„	„	„	1,260		.72
20,000	.0075	.114	5.6	2.84	23.5	7.5	259	14	8.8	19.6	12.3	6	208	17	11	23.8	15.4	800		3.4
„	.015	.144	2.8	2.92	24.96	15.0	518	„	„	„	„	12	416	„	„	„	„	874		1.87
„	.022	.174	1.85	3.0	26.4	22.0	763	„	„	„	„	17.6	609	„	„	„	„	940		1.3
„	.03	.204	1.40	3.08	27.84	30.0	1,036	„	„	„	„	24.0	830	„	„	„	„	1,010		1.08
„	.037	.234	1.11	3.16	29.28	37.0	1,280	„	„	„	„	29.6	934	„	„	„	„	1,080		.98
„	.045	.264	0.93	3.24	30.72	45.0	1,554	„	„	„	„	36.0	1,248	„	„	„	„	1,150		.82
„	.052	.294	0.806	3.32	32.16	52.0	1,800	„	„	„	„	41.6	1,439	„	„	„	„	1,215		.75
„	.06	.324	0.7	3.4	33.6	60.0	2,072	„	„	„	„	48.0	1,650	„	„	„	„	1,290		.7
„	.067	.354	0.61	3.48	35.04	67.0	2,314	„	„	„	„	53.6	1,854	„	„	„	„	1,352		.65
„	.075	.384	0.56	3.56	36.48	75.0	2,590	„	„	„	„	60.0	2,070	„	„	„	„	1,420		.61

APPENDIX IX.

Index to Paper.

(The numbers refer to the Paragraphs of the Paper.)

APPENDIX IX.

Index to Paper.

(The numbers refer to the Paragraphs of the Paper.)

Mr. Jacob.

Mr. F. JACOB (*communicated*).—The method proposed by Professor Perry (*vide* paragraph 59 of the paper) is, of course, the ordinary method of determining experimentally equipotential surfaces, and as adapted to the actual point in question will be found described by me in 1896, in *Electrical Review*, vol. 38, p. 497—and had been used for such purposes for many years by me at Messrs. Siemens Bros.' Works.

Mr. Swinburne.

Mr. SWINBURNE: In some ways I am sorry this paper was not read at length. We should all, probably, have learned a great deal more, because it is a very difficult and heavy paper to digest, and we should have had an opportunity of having the discussion postponed till another evening, and should probably, therefore, have gained more information.

Mr. O'Gorman has generously acknowledged a paper of mine at the Institution of Civil Engineers' Conference. He points out that that paper received very little attention. If this was so, I am afraid it was my own fault. The Civil Engineers' Conference was supposed to be for discussion, and I was asked to write a short paper upon which to hang a twenty minutes' discussion. I wrote the paper accordingly, but I am afraid it was impossible to carry on the discussion beyond twenty seconds, because the paper was absolutely unintelligible when it was read. It was very short, really dealing with such questions as that of grading. There were many figures showing sections of cables, but they were misinterpreted. I was not present at the reading of the paper, but I heard afterwards that there had been a very curious discussion, and that no one knew in the least what the paper was about. I then thought I would like to enlarge it into a paper myself, chiefly because that is the best way one can adopt of learning a subject—that is to say, the next best method to listening to a paper like Mr. O'Gorman's. Unfortunately I did not do it. I am very glad that Mr. O'Gormon has made some use of my paper, and, though he gives me a great deal of credit, I hardly think it is deserved; because he has developed the whole thing in a way that certainly was quite unthought-of by me. He has taken what little good there was in my paper to form part of his, and he has left out of it a great number of mistakes, for which I am very grateful.

I am only going to deal with one part of Mr. O'Gorman's paper, and that is the question of grading, as he has called it. I cannot help thinking that you may get into difficulties in some of these matters. For instance, take the case of a direct-current cable. The difficulty, of course, with the insulation, supposing it is uniform in resistance, is that the fall of potential is quickest in electrical conductors where the potential is greatest, that is near a point or a surface. The way to get over that difficulty is to cook the fall of potential by altering the specific resistance. When you are dealing with a direct current you are dealing practically with a conductor, and the author is going to cook this specific resistance till he gets a uniform fall of potential instead of a quick fall. But in his calculations I think he assumes that you can take a material of a certain dielectric strength, that is to say, you can take a material which you know will stand 20,000 volts per centimetre when it is flat, and he is going to alter the resistance of that by reducing it, but I doubt whether he will be able to do it with safety to the dielectric strength. I am afraid

Mr. Swinburne.

that all these simple calculations, when they are reduced to actual practice, will go; that is to say, the really best cable will be a matter of compromise and experiment from layer to layer, and not a thing that can be calculated out carefully. Exactly the same thing will probably hold as regards the specific inductive capacity. In a direct-current cable Mr. O'Gorman proposes to cook his resistance; in an alternating cable he is going to cook his specific inductive capacity; but I think it will be exceedingly difficult to cook either of those properties without altering the insulation in other ways. What we have to do is practically to get the best insulation we can for the price, and I do not know really how we are to get over the difficulty. I think the grading that Mr. O'Gorman points out, the cooking of the material, will help us a great deal, but I do not think it will go quite as far as that. We shall have to do a good deal more by altering the dimensions of the cable by using large cores and so on. A cable is very much the same problem as a gun. If we can only manage to do something corresponding to wire guns in cables it would be very nice, but I think we shall have to leave that, as it is so difficult. We want to get a thing that is polarised the wrong way all round the outside. The statement by Mr. O'Gorman that, under certain circumstances, say in an alternating current, the inner part can be broken down until you get to a place where the gradient is small enough to stand, is, I think, very dangerous, because I do not think the cable would stand that way. You might as well expect an old-fashioned gun to stand. With regard to the potential gradient, it is not a question of circulation at all. While I am pointing this out, I want to urge that a cable, if you treat it as having uniform insulation, or insulation that you can cook as to the capacity or resistance, is very tempting as regards mathematics. You can make it fit mathematics in the most useful way. Now that Mr. O'Gorman has started the scientific study of cables, I do hope that it won't fall into the hands of the mathematiculist and get into the state that our alternating current has—a whole lot of paper work that has really little to do with facts. The underlying assumptions of Mr. O'Gorman in this paper are perfectly valid, and, as long as we use them knowing their limitations, they can be of enormous value. As regards Professor Perry's method of plotting, as Mr. Jacob says, it is a very ordinary way, but so many of these ordinary ways are not known to us who are ordinary people. I think, therefore, we ought to realise that credit is due just as much to Professor Perry as if it had never been done before. There is always a tendency when a good thing is done by somebody before, rather to laugh at the latest person who has invented it; but it is just as difficult to re-invent a thing as to invent it. With regard to unbleached manilla, which Mr. O'Gorman advocates so strongly, in my old days, when I was working at condensers, I independently found that unbleached manilla was about as good as anything could be; but there was another material which also was very good, in fact in some ways rather better, viz., a paper called *butter-skin*. What butter-skin is I do not know; I think it is sold for packing butter in, and it is, therefore, not a water-proof, but an oil-proof paper. As far as I could see, it is a thin paper very heavily sized. I simply found that butter-skin would do, and as it did and was very cheap, I did

Mr. Swinburne.

not trouble about how it was made; but if it is a very heavily sized paper it is very curious that it should be useful, because it is the exact opposite to what Mr. O'Gorman told us we ought to use. The two things I used were unbleached manilla and butter-skin. I think Mr. O'Gorman hits the nail on the head as regards the action of heat when he points out that you ought to use unbleached paper. Anything that has been bleached has been to a certain extent ruined; nearly all bleached things are partially decomposed, and they very often have oxidising matters left in them which gradually act on them if they are heated.

I would ask Mr. O'Gorman, if I may do so, perhaps with a little prophetic forecast, not to judge of the value of his paper by the amount of discussion, because it is a very difficult paper to discuss. None of us really know anything about cables, except Mr. O'Gorman. In that remark I include the cable-makers. I do not know what the cable-makers will say in this discussion. I do not think they will say anything at all, and I think they will probably pretend they do so because they have so many secrets which they do not like to make public. Whenever industries have secrets, you generally find that the people are working in exactly the same way and doing the same old things, and are ashamed to let anybody else see what they are doing. I think, therefore, we ought to remember that discussion is no criterion as to the value of a paper. The paper that is most discussed is the paper that happens to have something that is in all our minds, and not a new paper on a new subject which very few of us have thought about, and which may be, therefore, the most important of all. This is, I believe, the first really scientific paper that has ever been written on the subject of cables. When we remember that cables occupy about half the capital of electrical undertakings, we must realise that this paper is as important as if we were discussing all at once boilers, engines, dynamos, transformers, meters, voltmeters, and everything else that we have been discussing in this Institution since we began.

Mr. Bright.

Mr. CHARLES BRIGHT: I am glad to find that even Mr. Swinburne speaks of the paper before us as a "tough" one! For my own part, I can only say that, though I have travelled in its company more than once by train, I have so far only succeeded in making its pages extremely dirty—sleep overtaking me on each occasion. It must certainly be admitted by every one that Mr. Mervyn O'Gorman has shown himself to be a great master of his subject; and one feels that, if only on account of its length, that this paper might well have been presented as an entire book between covers. At any rate, it will occur to many of us that Mr. O'Gorman would be singularly suited for producing the very companion to Unwin's "Strength of Materials" that he expresses a desire to see. This is a paper which, in my opinion, requires very careful study, and I should be extremely sorry to enter upon a close criticism of its contents without indulging in such beforehand. My remarks can, therefore, only be of a somewhat general character. On another occasion, however—after more closely studying the paper, and after I have had an opportunity of referring to various data of my own on the subject—I shall hope to deal with it in greater detail.

Mr. Bright.

I am rather inclined to agree with Mr. Swinburne on the whole, in the opinion he expressed that, as a rule, when manufacturers were "mysterious" in their replies, it might be taken as a sign that there was really no "trade secret" to be divulged. In the early days of cable manufacture there can be no doubt that some of the pioneers in this line had a secret or two up their sleeve, and were mysterious with some reason, to avoid competition. Nowadays, however, though no doubt some manufacturers have special processes of their own which, instead of being patented, are, perhaps wisely, confined to the knowledge of the smallest number possible; still, as a rule, where mystery prevails, it may be safely taken that this is either a sign of "rule of thumb," or very old, methods being the order of the day, or else it forms part of an attempt to induce the inquirer to believe that special processes are in use such as no other manufacturer has the advantage of.

Though, as I said before, I have not studied the paper sufficiently to review it at all closely, I noticed one remark in the course of what Mr. O'Gorman has read, or said, to-night, that I will lightly touch on. I think the author implied a doubt as to whether indiarubber did not absorb water, and seemed to suggest that this was a matter which was not yet known about. Without wishing to be abused for pointing to ancient history, I would remark in reply that this matter was settled for us in the early sixties—*i.e.*, somewhere about 1861—by the late Sir William Siemens, who showed distinctly from a number of tests published in a Royal Society paper, that all known mixtures of indiarubber, vulcanised or unvulcanised, absorb water, but only when under a very definite pressure, such as would not be present in the case of underground cables.

With regard to the question as to what is the best resistance for indiarubber or other insulating material, I would remark that the signification of a good insulating material—and by that I mean a durable material mechanically, a certain and sufficient degree of insulation resistance being assumed—is, I venture to think, purely a matter of experience. That is to say, it has been found that, if indiarubber has an abnormally high insulation, we know by experience that its substance is not a durable one mechanically and that its electrical resistance will gradually fall to a low ebb. On the other hand, we also know by experience that it is not natural for a rubber mixture of good quality to have an abnormally low resistance value : in fact, by experience we know within what limits the specific resistance of rubber should range (if it is made of a suitable material), and we also know what the value should be for other materials by experience, if suitably composed and properly manufactured. Whilst on this subject I would say that I consider that any advantage which may accrue to materials of a sealing-up character are more than counterbalanced by their unreliability and non-durability, as well as by the fact that it is almost impossible to localise faults in them satisfactorily. And here I would like to remark that the advantage of a high resistance for purposes of fault testing should be regarded as one of degree only. Certainly abnormally high resistances are not warranted solely on this account,

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Mr. Bright. for it must indeed be a low insulation which will not show the position of a fault to anything approaching a skilled electrician. In this connection I should like to confirm the author's opinion that the only absolutely satisfactory way of testing a dielectric is on a length of actual cable. As regards what may be termed cheap imitations of vulcanised rubber, any of the numerous "ites" introduced are, as a rule, merely imitations of rubber mixtures; if not, they usually prove to be failing in durability. Notwithstanding the wide scope of this paper's title, I have not discovered that gutta-percha has been dealt with. This gum still stands its own for submarine work; and here the "grading" which Mr. O'Gorman speaks of is, I think, already provided for to some extent.

It took some time for those concerned in electrical undertakings to depart—even tentatively—from the ordinary, but expensive, methods of insulation, the good results of which were a more or less certain quantity. This was but natural when we come to remember that the object of those who put their money in engineering enterprises is to make more money rather than to pursue scientific research, though inadvertently they often also effect the latter object. New methods and materials are frequently tried, but as a rule the experiment is less risky where the newly tried one is of a low initial cost compared with cables. One may almost go further, I suppose, and say that probably we should never have seen the newer and cheaper methods of insulation now so largely in vogue for electrical underground mains but for the difficulty of raising capital for undertakings where so much had of necessity to be sunk initially in the mains themselves, this amount being almost prohibitive with some systems and in some instances, in the case of rubber.

But even then the advocates for cheaper insulation had great difficulty in persuading financiers and business men to adopt their ideas, for those who had been associated with insulated telegraph wires for many years all looked askance at these newly proposed methods. They had, indeed, themselves tried them experimentally with dire results. Thus it redounds very much to the credit of the initiators of prepared paper insulation for Light and Power Mains that they not only induced business men to adopt paper-insulated cables on a large scale, but ultimately overcame the difficulties which were at first so formidable in the way of moisture creeping in at the joints, &c. And here we naturally call to mind Mr. Ferranti's plodding pioneer work at Deptford. The same remarks apply—though perhaps in a less degree—to the bare copper mains introduced by Mr. Crompton and others with such good results. But for these cheaper methods of insulation for mains, there is no doubt that we should not have the satisfaction of seeing the already large mileage of electric light circuits all over the world we now do, for the necessary capital would never otherwise have been forthcoming. I have ventured to bring forward this point, as it occurred to me as one suitable for comment in connection with the discussion, and because I thought it would come better from any one like myself—more associated with what might be termed the older methods of insulation—than from many of those present. Finally, I

should like to join in heartily congratulating Mr. Mervyn O'Gorman on his very excellent paper. Mr. Bright.

Mr. G. L. ADDENBROOKE: I had a good deal to do with cables some twelve or thirteen years ago, and was constantly down at Silvertown and Hanley. It was an exceedingly difficult question to probe into; and I am afraid the superintendents there did not like me at all. I was always asking questions and wanting information, and there was always something that one could never get at. And that has been my feeling very largely ever since. When you begin to calculate in the case of electrical power transmission, it is wonderful what can be done if you have only copper to deal with. Of course, over a great part of the world they have very little except copper to consider, because the use of overhead wires is allowed. You spend, say, £100 a mile in putting up the standards, and with a bare copper wire it is extraordinary what you can do in the way of transmission, the distance you can go, and the cheapness with which you can generate at a central station or at generating stations at several points. Of course, we in this country are so far in a different position. Mr. Addenbrooke.

There comes in this question of insulation, and there is nothing but this question between us and objects of the greatest economic and industrial importance. It has always been a wonder to me that more attention has not been paid to the subject. Although a great deal of work has been done by cable companies, I cannot help thinking that, with our modern knowledge and experience, the subject ought to be taken up in just such a way as Mr. O'Gorman has treated it. It is true that Mr. O'Gorman does not, in his paper, give us actual practical results, yet he has opened up the whole subject in a scientific and proper manner. Whether his conclusions are right or wrong, seems to me to matter little at this stage. When you are in such a position that you do not know what to do, it is best to put down on paper all the facts and all the reasons you can give, whether you are right or wrong. Once get them on paper, you see clearly the problem, and you can begin to make progress. I feel unequal to discussing the paper technically to-night, owing to my not having had time to give it proper consideration in detail. I may send a few remarks in writing later on; but I do think we owe very great thanks to Mr. O'Gorman for his paper, and I hope something will be done to get good results from it. Cable-makers are now wealthy, and can well afford a little money for experiments, and I am sure we cannot possibly have the best form of cable without much further experiment. Really scientific and carefully conducted experiments, persisted in for a long enough time, are bound to result in great improvements, which would be of enormous industrial benefit.

Mr. J. E. KINGSBURY: Any unwillingness that there may be on my part to speak arises from my inability to give any points of practical value on the scientific part of Mr. O'Gorman's paper. I should like to join with other speakers in congratulating Mr. O'Gorman and the Institution on the presentation of the paper. I do not quite agree with Mr. Addenbrooke that it does not matter whether the figures are right or wrong. I wish I could say either that they are wrong or that they Mr Kingsbury.

Mr. Kingsbury.

are right; but I am not prepared to say so, and that largely arises from the fact that so much matter is dealt with in this paper that it must be difficult to digest it all. Mr. O'Gorman has given us a very full meal. Its value from the nutritive point of view cannot be considered till it has been digested, and I think there has not been sufficient time yet for the operation. It is, however, suggestive, and I do not doubt that electricians and cable-makers will be unanimous in getting any good there may be out of it. Although I am unable to discuss that point, there are some opening paragraphs in Mr. O'Gorman's paper which I think call for some remark. To some extent I think Mr. O'Gorman makes observations in regard to cable manufacturers and purchasers which are not merited. It is not a fact that the purchaser does not care what he buys. I do not think it is a fact that cable manufacturers are unregardless of the material that they put into their cable. Cable manufacturers, I suppose, like very ordinary mortals, manufacture cables for a living. They have a position of very great responsibility, and I think they feel their responsibility. In the introduction of any new article it must either be something that the purchaser knows is durable, or it must be something that the purchaser is content to take on very specific guarantee from very responsible people. When Mr. O'Gorman "supposes" that we might get an insulator which has as low a capacity as air and will last for one hundred years, I do not see why we should not suppose it. In point of fact, I do not see how we could do anything else; we shall certainly not be in existence to prove it. But people who buy cables are very particular. They do not want to "suppose" any more than they can help, and if they can have a material which they know has lasted one hundred years, I am inclined to think they will have more confidence in it than something which is only supposed or alleged by the designer to last for one hundred years. They do look for results, and I think that they are justified in doing so. They put a great deal of money into cables, and what they get they expect to be good. That only relates to the opening remarks of the paper. On such points I am inclined to think that perhaps Mr. O'Gorman has generalised from a limited experience. That aside, I think he is entitled to our heartiest thanks for the very great trouble which has been involved in connection with the paper. He must have put a good deal of brains into this paper, and I think that we are highly indebted to him for it. I hope it may result in something practical and of benefit to the Institution and the industry.

Mr. Ferranti.

Mr. S. Z. de Ferranti: All cable-makers will, I am sure, be very much interested in this paper. It contains an immense amount of matter for thought and careful work. At present cable-making, which is apparently a very simple process, receives the greatest possible care. The money-interests are so large, the value passing through weekly is so enormous, that any properly conducted cable company constantly uses the very greatest care to try and make the best cable they possibly can, especially considering the great competition there is, and with a view to making all sorts of small savings and to gaining slight advantages over rival manufacturers. With regard to the paper itself, what I think of most interest to the electrical public generally is Mr. O'Gorman's

discussion of the most economical voltage, the most economical size of cable, and the particular style of cable for transmission of various powers to different distances. This is a matter which may be understood by some few; but still it wants very careful consideration, and it is a very good thing that Mr. O'Gorman has brought it up for consideration in the middle of his interesting scientific paper. It is quite surprising, when you come to work out questions of electric transmission and distribution, to find out, for example, under practical conditions, what the best voltage is. To begin with, it will depend upon the size of your scheme, and to a very large extent upon the number of points of distribution to which you have to take your power It is very curious to see how a higher voltage in some cases is less economical than a lower one. Copper is quite a small factor in the total cost. Insulation may be much more serious, and in a case that I have in my mind I remember being exceedingly surprised to see that a 10,000-volt transmission, although the distances were considerable, was nothing like so economical as one of 5,000 volts. When I speak of transmission, I mean transmission and distribution. It is not a simple case that Mr. O'Gorman has given us of transmitting a certain power to one specific place, but it is when you have got to transmit it to distributing centres, and then from those centres radiating to a number of customers or points of consumption of various size. It is a thing which any member of the Institution who is interested in this particular point would find very valuable to work out as a test case. Then another feature is this: you commence with a scheme of a certain total capital expenditure, for example, to distribute a certain number of kilowatts over some given district. You find that one voltage is the most economical to start with, but if you assume a certain development over a certain number of years—of course it is a variable amount, and you must use your best judgment—you will see that the starting voltage is no longer the voltage for working at later on; and so it is really very hard to calculate what is the best thing to do. It is largely a matter of good judgment, which I suppose would come from good natural sense, and I won't say from a prophetic eye, but from something of that nature. It is very much of the nature of a speculation, in fact, to know what are the best voltage and the best lines to go upon in a case of this kind. It really depends upon the rate of development and many other things that make it most complex, Then the thickness of dielectric for these high pressures is quite a serious matter. I think it is borne out in the paper that thicknesses are too great, according to the Board of Trade rules, where cables are large. That is a point I feel very strongly upon, because I think it is one of the things which to a certain extent handicaps the industry of distribution on account of its adding, perhaps unnecessarily, to the total cost. These high-tension cables are mostly paper-covered, and then covered with lead. It is not only the question of more insulation. but also that of the much heavier lead, and with lead at the price we have recently been paying, it is a very serious matter indeed. The Board of Trade rule is apparently a very simple one, and it may or may not seem curious that it exactly corresponds to the 10,000-volt mains

Mr. Ferranti.

Mr. Ferranti. originally laid from Deptford, which had a radial thickness of half an inch of insulation over the inner conductor. That comes out to fit the rule exactly. The rule came after the mains, and no doubt it was a practical way of dealing with the subject. It was less likely to be wrong than saying something else. With regard to the question of cable-makers and their not liking to speak in the discussion, I do not know whether I have told you anything that is not the common property of all cable-makers. I think cable-makers who do know their business —that is to say, all the leading cable-makers in this country—have practically no secrets. I am sure I should like to have some. I would rapidly convert them into patents, and I do not doubt that I should get some most pleasant results from them as regards cable-making. But you may take it that practically there are no secrets. The thing is very plain. It has got down to be a very common industry which is very carefully supervised. It is essentially a financial operation, and that operation is to make the maximum profit with a view to a lasting business. That is really the only secret there is in cable-making to-day.

Mr. Scott. Mr. E. K. Scott: I have been looking into this question recently, and I think that for moderate voltages, say 2,000 or 3,000, the semi-solid system, as it has been laid down at Chatham, Rochester, Worcester, and other places, is more expensive than the paper-covered cable lead-covered and laid in bitumen or otherwise. When you come to 20,000 or 30,000 volts, however, you want something that will stand: it is not a question of expense at all. Suppose you wish to put down a paper-covered cable for 30,000 volts, then according to the Board of Trade rule you must have the paper on the cable at least 1½ inches thick, that is altogether 3 inches of paper, which means running the cable through the covering machine about 20 times. There is the great expense of covering, and then, when you have done, the conductor is 3½ inches in diameter and you must put on lead at least a quarter of an inch thick, which means that the lead alone will cost about £600 a mile—after which it would require something in the nature of a traction engine to draw in such a cable. Above all, I think the cables that we shall have to use from now onwards will be cables to draw in, for people will not stand this dragging up of the streets every day. Of all cables the paper-covered cable is the worst to draw in, for when bent the insulation does not go back like rubber, but the layers of paper slip one over the other and do not go back into place properly. It is, however, the oil on the paper that is depended upon for insulation, and in the Brooks main you have *all* oil, which is the very thing required. There is, of course, the jute to protect the cable whilst it is being drawn in and to support the conductor from the bottom of the conduits. It might be thought that the fact of the conduits having all been made of cast iron would be a disadvantage; but they need not be iron. The porcelain conduits that are now on the market form an insulation in themselves. They are made in about 3-feet lengths, which means a good number of joints, but you can make the joints sufficiently oil-tight for a Brooks main because the oil is very viscous indeed; immediately it gets through a leak it becomes hardened and seals the leak. Where one does not want

to make a joint every few hundred yards or so, I think there is a good deal to be said for the Brooks main. If there were a number of joints there would be an objection to this type of main; but in the case of an important extra high tension feeder running out some distance to a substation, I think there is a good deal to be said for it. Mr. Scott.

Mr. F. C. RAPHAEL: Very much has been said in praise of Mr. O'Gorman's paper, but I would like to add my tribute on one feature which I do not think has been mentioned yet. He spoke about the degradation of rubber, but, to his credit, he did not follow the general fashion and speak of the degradation of the British electrical engineering industry, which has been dwelt upon very much lately at this Institution. The reason, I am sure, is that the British cable industry is certainly in no fear of decadence at all. We still stand first, and we are likely to do so,—although there is the fear of stagnation which Mr. O'Gorman has alluded to, and in connection with which he suggested that we should follow out more systematic methods, and pay more attention to the laboratory. Mr. Raphael.

Mr. O'Gorman's paper on the insulation of cables commenced with some figures to demonstrate the importance of the cable industry. I would like to point out that these millions of pounds are to a large extent copper and not insulation—that the cost of the copper sold in cables is ever so much more than that of the insulation. I am therefore surprised that the author considers high-pressure cables to be more profitable than low-pressure cables to the cable manufacturer. One might almost have applied his argument to a consulting engineer who gets his 5 per cent. commission on the actual expenditure on the installation, and say that it pays him better to design the switchboard than to design the cable network—allowing ample provision for extensions.

To come to a more practical point, Mr. O'Gorman spoke of an ideal dielectric, in which the leak made by a high-pressure discharge would seal up. I believe some recent cable specifications have contained this provision; anyway, people have an idea that it is a new thing, and that all good dielectrics nowadays have got to seal up, if by any chance the insulation sparks through. I cannot agree that this is good. Any automatic device which cannot be supervised is liable to get out of order. If you shut away an automatic machine in a cellar, and are unable to visit it, it is sure to get out of order in time. A self-sealing fault in a cable is purely an automatic device, and the longer it works, the worse it gets. Suppose a cable sparks through, and the fault afterwards seals up. A little time later you get possibly the same effect of capacity or induction, and a rise of pressure, and the cable will spark through again probably at that place. I had some experience in that direction ten years ago, long before these self-sealing dielectrics were considered a good thing, and we found them a regular nuisance. We found, say, that a cable connected up to a station switchboard would spark through and cause the fuses to go. If it was put on again, it immediately sparked through; but, on disconnecting it from the switchboard and testing it later on, when one could disconnect the main sufficiently, one found that the fault had sealed up and could not be localised. If we put on the

Mr. Raphael. machine again, in the course of a few hours or days the cable would spark through as before. I have subjected faults like that six or seven times to currents which blew the fuses, and yet they have not broken down, and I could not find them. I have subjected a fault that blew a fuse at 2,000 volts repeatedly, to 4,000 or 5,000 volts before I could get it down to the number of ohms necessary to localise the fault. It would be ever so much better if these cables did break down straight away. The switchboards are fitted with automatic devices, and we have disconnecting boxes on our networks. Between midnight and dusk the next day you could easily find the fault, cut it out, and repair it. That is not nearly so much trouble as if you are constantly in fear of the fault breaking down at any time.

I would like now to come to the question of high insulation. Mr. O'Gorman admitted that high insulation in cables is good in the feeders, but did not consider it necessary in the distributors. It is, however, not a question of when the mains are under the ground; it is a question of testing them in the factory. If you have a cable of 10 megohms per mile, and you put it in water for twenty-four hours, if there is a slight leak in it, it will not get lower than the 10 megohms; whereas, if it has normally a greater number of megohms, you will find the leak and repair it, and you will not be sending out a bad cable. This matter is often confounded with the question of what one may call abnormally high insulation. If you have a bad cable, say a bad fibrous cable, testing 200 or 300 megohms per mile, which probably shows that it is not properly dried out, you can easily strip that cable, put it in the tanks, and bring its insulation up to a thousand or more megohms per mile, but at the same time weakening the insulation mechanically. That does not prove that in general high insulation is bad. As a general rule, a good cable with a high insulation will be better than a good cable with a low insulation, assuming the same insulating material in the two cases. There cannot be any doubt about that; it seems almost ridiculous to say so, and yet people argue, probably because it sounds a very pretty paradoxical statement, that, if your insulation is too high, the cable is bad, and if the insulation is low the cable is probably very good indeed.

I am rather diffident about speaking on the question of the "grading" of insulation, as it is a very new thing. I believe, though I am not quite sure, that I noticed some cables at the Paris Exhibition, exhibited by the Société Industrielle des Téléphones, with vulcanised rubber round the copper, and paper over this under the lead. That would, I suppose, roughly be something in the direction indicated in Mr. O'Gorman's paper. There is one point not to be forgotten. Mr. O'Gorman stated that a very high factor of safety is employed now. The reason for this factor of safety is that we are dealing with mixtures of very complex organic compounds, which one cannot express by any chemical formulæ. Moreover, they are not easily reproducible with accuracy. The same applies to the tape, paper, etc.; you cannot always be sure of procuring exactly the same sort. In the case of a cable with a carefully worked-out insulation, these difficulties are ever so much increased. The same applies to the various unavoidable accidents in manufacture, such as

the introduction of impurities. You get these impurities as before, but you have a smaller range of thickness to rely upon, so that the least impurity will cause the cable to spark through and break down, not in the factory, but after it has been sent out—a thing that all cable manufacturers are anxious to avoid as much as possible. Mr. Swinburne has already pointed out that there may be a flaw in Mr. O'Gorman's theory. No doubt Mr. O'Gorman will be able to get specimens of such a cable made, and then perhaps we shall have another paper of equal excellence to this one, but giving results, and showing whether we have any hope of diminishing the cost of cable in the way Mr. O'Gorman indicates. Mr, Raphael.

Mr. STUART A. RUSSELL (*communicated*): In looking through Mr. O'Gorman's paper, the point which first strikes one as of most interest is naturally his suggestion as to the grading of the dielectric, so as to obtain a uniform distribution of the voltage stress. This suggestion is a most interesting one, and may, if it can be practically applied, lead to a considerable cheapening of cables for high pressures, provided that the Board of Trade will abolish their existing rules for the thickness of dielectric. Mr. S. A. Russell.

It is, however, a difficult question to discuss until experimental work has been done on it; and I can only therefore make a few general remarks as to some of the difficulties which I should expect would be encountered in practically carrying out such grading.

The first point naturally is the danger of affecting the dielectric strength by our efforts to produce dielectrics having a regular gradation in the values of their capacity and megohm resistance; and I think a greater difficulty will be found in dealing with the capacity question than with that of resistance. There is a further point with regard to the permanency of these specially-arranged values of capacity and resistance which will, I think, necessitate experimental work continued over a considerable period, before it would be safe to lay down cables manufactured in this way for high-pressure work; as the effect of ageing must assuredly be carefully studied, as it would be a most serious matter if, in ageing, the pre-arranged capacities or resistances should change in such a way as to considerably alter the distribution of the voltage stress.

Passing on now to some of the statements made in the paper, I think that Mr. O'Gorman hardly gives sufficient credit to manufacturers and others with regard to the amount of technical work that has been done in connection with cable making. If he will refer, for instance, to the papers by Preece, Siemens, and Hughes, reprinted in the journal of this Institution for 1892, and will read these papers and the discussions, he will, I think, find that many of the points now being considered, such as the relative effect of high-pressure currents from transformers and from induction coils or influence machines, the relation between disruptive strength and megohm resistance, and the effect of ratio of outside to inside diameter of dielectric on the disruptive strength of cables, were already engaging the attention of many workers. As an example I would refer to his statement that, "It is only two years since the discovery was announced by Steinmetz that the disruptive effect of a sinusoid alternating voltage on heavy oils is

Mr. S. A. Russell.

greater than that of peaky volt surgings from an induction coil or high-frequency oscillations. Should not this have been known many years ago?"

It was, I believe, known to a good many people, and in the discussion on Professor Hughes's paper, already referred to, on "Oil as an Insulator," Mr. Campbell-Swinton gave this explanation of the difference between the results he obtained with an induction coil and those obtained by Professor Hughes with a high oscillation discharge; and Mr. William Gray offered this same explanation to show why Professor Hughes got such different results from those which had been obtained in tests made by us with an alternating current transformer at Silvertown in 1891.

There is one other point I would like to refer to, and that is Mr. O'Gorman's conclusion that the disruptive strength of dielectrics always decreases with increased thickness, as I consider it as possibly incorrect, and at any rate very misleading in dealing with the disruptive strength of manufactured cables. I am not in a position to say that his conclusion is actually wrong, but a few experiments made ten years ago at Silvertown on thin sheets with electrodes of large area, do not appear to bear out his conclusion; and I am inclined to think that the comparatively small size of the electrode as compared with the spark gap, has much to do with the result of tests to which he refers. Unfortunately in quoting T. Gray's tests on oils, the author of the paper does not give any information on this point; but, seeing that gaps up to 10 centimetres were employed, the size of the electrodes would have had to be inconveniently great to get uniform stress lines. Whether his conclusion is correct or not as regards the disruptive strength of uniform sheets, such results cannot be applied to cables, as unfortunately there always do exist imperfections of manufacture, a point which is of course, fully realised by Mr. O'Gorman, and mentioned in the paper. The effect of such imperfections is relatively much greater in the case of thin coverings than in the case of thick ones, more especially in all cables where a thick covering is obtained by putting on successive coatings, and is not all put on at one operation. The consequence is that, in practice, we find exactly the opposite result; that is, the apparent dielectric strength of cables undoubtedly increases with the thickness of the covering for all such sizes as are now in use.

I am not, of course, only comparing two cables with the same sized conductor, although even in this case, with such values of $\frac{D}{d}$ as are commonly employed, this rule holds good; but am more especially referring to the case where two different sized conductors are covered to the same ratio, so that the distribution of voltage stress shall be similar in both.

Mr. O'Gorman.

Mr. M. O'Gorman, in reply (*communicated*): I at first thought that, as Mr. Swinburne suggests, there might be difficulty in "grading" cables for the very reason that he names. The question was, Can we obtain substances having a large specific capacity for the inner layers, and at the same time no less disruptive strength than the materials ordinarily used in the outer layers? It was to verify this amongst

Mr. O'Gorman.

other things that Appendix I. was drawn up. That Appendix gives a sufficiently favourable answer. It will be seen that by a fortunate coincidence the materials of higher capacity are usually materials of greater disruptive strength. I do not think it would surprise investigators if experiments on purer materials showed that this coincidence became a law. For the present the coincidence is sufficient. In my abstract of the paper I did not draw sufficient attention to the fact that "capacity grading" by loading or by impregnating paper, or by using gums and oils, etc., is the only "grading" of immediate practical interest—(i.) Because high pressures are almost always alternating. (ii.) Because the oils and gums available for high capacities are in constant use in almost exactly the manner I propose, save that they are arranged in the wrong order. (iii.) Because even were continuous high-tension cables employed, the maximum stress would in all probability be due to varying pressures arising when circuits having self-induction or capacity are broken.

It has since occurred to me that until one has thought about it, it is not obvious that for alternating currents, the *conductivity* of the different layers of the insulations ought not to be "graded." At ordinary frequencies, even as low as 25 cycles per second, the potential between the plates of the elementary condensers in which I considered the dielectric to be divided in Fig. 5, Par. 54, is not affected by leakage through the condensers. Any individual condenser would require a time greatly in excess of the interval between two half periods to discharge itself through a few megohms. The time of discharge would probably be of the order of hours and not fractions of a second. I myself had overlooked this point at first, and was confronted with the apparent necessity of grading all cables both for capacity and insulation resistance, and the search for an appropriate insulator was thereby rendered very much more difficult. As things are, however, I hope to get a 37/14 10,000-volt cable made in accordance with the particulars given in Paragraph 60, with 30 per cent. saving of insulation and lead. The grading for conductivity, were it required, would be easy enough without impairing the disruptive strength of any layer, witness the example in Par. 47. This is due to the enormous range of insulation resistances possessed by the different well-known dielectrics which vary by millions of megohms.

I had feared that some one would object to my apparent neglect of skin resistances between metal and oil when calculating the percentages of castor oil to be added to the insulation in Par. 60. Actually, the drop of volts in crossing the skin may be taken to diminish the effective maximum stress and not to affect the shape of the curve of stress or the proportions of each oil used. The skin resistances of different substances varies: paraffin wax, for example, when in contact with copper apparently shows very little skin resistance, hence paraffin wax must be very strong if it is to compete in thin layers with a substance which shows very high skin resistance. For this reason, petroleum oils which contain paraffin wax in solution ought not to be used for smothering a high-tension spark. Mr. Swinburne compared the resistance of a gun to the puncture resistance of insulation. This is a

Mr. O'Gorman.

particularly happy simile, but I do not think it should be pushed so far as to constitute an argument against the likelihood of a brush discharge occurring in dielectrics other than air. Nevertheless, I think that a cable-maker should have the solution of the gun problem clearly in his mind when he is asked to design a cable for hitherto unused pressure. It will infallibly give him a desire to try "grading."

I must, of course, agree with Mr. Swinburne that altering the relative radii of the conductor and insulation is the simplest way of keeping the voltage gradient within safe limits, but I do not know that increasing the size of the conductor, or using aluminium as suggested in Paragraph 102, has before been considered as a possible way of withstanding higher pressures. It only occurs in exceptional cases, but it should be of value. These cases must be worked out by the cable purchasers and consulting engineers, as it does not seem to be the cable maker's business to show the engineers that a larger cable can be got for less money, nor to make a number of estimates gratuitously in order to diminish the value of their orders. It is doubtless useless to hope to do away with altering the dimensions of cables to stand high pressures. I should be satisfied if only 10 per cent. were economised on all high-tension cables by means of "grading." I shall take an early opportunity of trying the value of "butterskin."

I am sorry to find that, except Mr. Kingsbury and Mr. Russell, cablemakers have largely fulfilled Mr. Swinburne's prophecy in the discussion, but this is probably due to the fact that they have not the time to talk about cables; they are so busy in making them. Mr. Russell's expectation of difficulty in grading capacity I fully sympathise with, but as I pointed out above, it solves itself. The higher capacity substances *have*, as a rule, the higher disruptive strengths. Whether loaded paper, gums, or viscous oils will remain permanently in their "graded" order is a very pertinent consideration, and I am glad it is raised, although it is dealt with in the paper. Several things might tend to disturb the prearranged order—among them are diffusion, electric attraction, and gravity. The most dangerous is electric attraction, but here, again, the difficulty resolves itself. The tendency of dielectric materials under electric stress is for the materials of high specific capacity to group themselves along the lines of greatest stress. An elementary example of a material of high specific capacity immersed in a matrix of lower specific capacity is a pith ball in air. It moves towards the place of greatest stress, say towards a charged brass ball, *regardless* of its polarity. This is important. We see here that with alternating potentials as well as continuous, the materials of high capacity move towards the conductor and not towards the sheath, because the stress lines are greatest near the conductor. See footnote to Par. 57. This tends automatically to prevent derangement of "grading."

Diffusion at ordinary temperatures is known to be unimportant in the case of paper impregnated with oil, because it is resisted by the greater force of capillarity. Also, the diffusion will depend on the relative densities and viscosities of the oils and gums, and even if these qualities were as divergent as the specific inductive capacities (which they are not, in many cases, at ordinary temperatures) the tendency to diffuse would be small.

Mr. O'Gorman.

Gravity, aided and abetted by the expansions due to changes of temperature, might be feared were it not so easily combated by the use of substances which practically solidify. We can thicken rosin oil with palm oil or substances like rosin; we can use gums like rubber, and materials which stiffen with oxidation like linseed.

Mr. Russell refers me to the papers by Preece, Siemens, and Hughes in 1892, and I may say that I had not entirely neglected these papers before writing my own, which is on very different lines. In Appendix I. will be found some of the results which were published in these early days, and their author's name is duly acknowledged.

Sir William Preece's paper was valuable in 1892, but space did not allow of a discussion of points raised so long ago, especially as opinions were then so very conflicting. I will take one or two examples. He thought that 5,000 volts per centimetre of insulation was probably as much as could be safely permitted in practice. Clearly it would be a refinement to discriminate between the sine waves and peaky waves to which an insulation might be submitted when the maximum safe pressure is named at a figure which is now quite out of date. With regard to Mr. Siemens' paper, it will be remembered that he expected the distance through which a spark would penetrate would be greater, the greater the frequency. With frequencies of 80 and 100 he found no appreciable difference. Professor Hughes, on the other hand, found that oil was very superior to air and gutta-percha at high frequencies (and presumably when the waves are not sine waves), and I am obliged to Mr. Russell for pointing out that Northrup and Pierce were forestalled by Hughes and Swinton in this matter. Sir William Preece actually proposed that the thickness of the coating should be such that after it had cracked, through age or accident, the air which might fill that crack should be sufficiently thick to prevent puncture. He took (with a puncture distance of a millimetre of air) 600 volts, whereas we are now fairly sure that the stress depends not only on the volts, but on the relative curvatures of conductor and sheath as well as on the voltage gradient in the air and on the skin resistance between air and metal, and that apart from skin resistance it is about 27,000 volts per cm. I think that Mr. Russell himself pointed out that if a crack did occur, the surfaces of the crack would nullify all considerations of what was the strength of air between conductors.

Mr. Russell misunderstood, I think, my remarks about the disruptive strength of dielectrics. I will restate the position as follows, and he will then possibly not disagree. When there is a gap between two conductors, the resistance of that gap (to puncture) often consists of two parts: (1) the specific resistance of the insulation, which is very frequently a constant for all thicknesses. (2) The skin resistance offered by the surface between conductor and gap, which is apparently a constant for any one metal and any one insulator. When the gap is small the resistance due to (1) is small, but that due to (2) is large with substances like linseed oil, castor oil, vaseline, N.W. Virginia crude oil, air, etc., and consequently in all these cases (and apart from impurities) the total strength of the gap in resisting puncture measured in volts per cm. of gap is less for large than for small gaps. T. Gray and

Mr. O'Gorman.

Lombardi's experiments confirm this, as also does the experiment Mr. Cozens-Hardy made on the lecture table in illustration of my paper. There are exceptions to this subdivision of the strength of a gap into two parts: one occurs when the conductors are carbon in air, the other when the gap is full of certain qualities of paraffin wax (the stress curve of which is given in Fig 12.)

The paper on the strength of oils by T. Gray does not, I think, mention the size and shape of his electrodes, but as his former and fuller paper (*Phys. Rev.* 7, pp. 199–209; 1898) gives details of the very large and slightly curved electrodes used, I think Professor T. Gray's results can undoubtedly be taken not to suffer from the elementary error Mr. Russell suggests. I would thank Mr. Russell for his contribution to the discussion.

Mr. Bright remarked that Sir Wm. Siemens had shown that all known compound mixtures of indiarubber absorb water; but this has little value, because so far I have been unable to find any published results which show the constituents of the compound rubber which was found to fail, or the effect, improvement, or otherwise of varying these constituents. It does not even appear proved that pure *un*compounded vulcanised rubber does absorb water when it is not under the very definite pressure to which Mr. Bright alludes. Mr. Bright gives point to the mechanical test on compound rubber named in Par. 37, and detailed during the reading of the paper, by saying that a cable rubber having abnormally high insulation is known by experience not to be durable mechanically.

I am glad to admit Mr. Jacob's claim that he has very clearly indicated the method which I ascribed to Professor Perry of determining the potentials within the thickness of a dielectric by making a model and using a needle point upon a sheet of platinum.

When Mr. Raphael points out that of the total cable turnover a large proportion is copper he is right, but with extra high-tension cable the major part of the capital expense is for materials other than copper, and his contrary opinion based on an error; thus on a 37/14 cable for 10,000 volts (single, paper-insulated and lead-covered) I happen to have recently made the estimate, and the cost is divisible into three equal parts—£100 insulation, £100 copper, and £100 lead.

I agree that it is futile to specify for cables which shall seal up a fault, but in the hypothetical perfect cable spoken of in Par. 2 it would be an advantage if, after an abnormal rise of pressure due to some such cause as breaking an inductive circuit or where the break was shunted by a condenser, the ensuing puncture were to become perfectly healed for all working stresses.

As for the detection of partially self-sealed faults, it is usually possible to carbonise the fault by maintaining a high-pressure current through it and then it is easy to find. Mr. Raphael makes a plea of high insulation for the sake of easily finding the fault in the factory, though he is apparently willing to admit the claim that low insulation is good enough once the cables are sound throughout and laid in the ground. As he and I served a similar apprenticeship by working for several years in the same cable factory, I do not like to differ from him radically, but

I believe he himself would quickly devise, if he has not already done so in his book, a high pressure test which would search out all the faults as well as is now ever done on 1,200 megohm cables. In the paper I have not touched on bad cables stripped of lead and re-tanked and re-covered. The paper is too long already. It is quite possible to detect when the fibre has been deteriorated by over-heat or torn by the stripping tool, but it is useless at present to explain the signs of this. In saying that cable insulations are not reproducible with accuracy because their chemical formulæ cannot be written down, Mr. Raphael forgets that their specific capacity is reproducible with accuracy and can be written down even when their specific insulation is very variable, and it is just this property which I propose to utilise in "grading." Mr. O'Gorman.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :— The President.

Members:

Carl Hering. | C. Odilon Mailloux.
George Alfred Neale.

Associate Members:

James Kerr Bock. | Albert Edward Pullen.
Ivan Fawcett Fawcett. | William Smethurst.

Associates:

James Cairns. | John Edward Field, Junr.
James Stormont.

Students:

Herbert Lancelot Coyle. | James Douglas Kendall Restler.
Alexander M. Nicolson. | Frederick Eaton Robinson.
Raymond Walter Thompson.

The Three Hundred and Sixty-First Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 14th, 1901, Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on the 7th of March were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that the list should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

Ernest Kilburn Scott.

From the class of Associates to that of Associate Members—

C. D. Taite.
William Wyld.

From the class of Students to that of Associates—

Percy W. Freudemacher.

Mr. W. W. Cook and Mr. H. L. Leach were appointed scrutineers of the ballot for the election of new members.

A Donation to the Library was announced as having been received since the last meeting from Monsr. C. H. Julius, and to the Building Fund from Messrs. R. H. Benham, W. P. Digby, H. W. W. Dix, and M. Solomon, to whom the thanks of the meeting were duly accorded.

SOME NOTES ON POLYPHASE SUBSTATION MACHINERY.

By A. C. EBORALL, Member.

Polyphase systems of generation and transmission, combined with direct-current distribution from substations, are very much in evidence at the present time, in connection

with many large lighting and traction schemes, and there is little doubt but that the use of such combined systems will greatly extend in the future for those cases where power has to be supplied in very large amounts over large areas. The author thought, therefore, that a paper embodying some notes on the subject might be of interest to many members of the Institution; and, complying with a request of the President, the scope of the paper has been confined as far as possible to practical questions of everyday working that have come within his own experience. Consequently, many of the points discussed must be quite familiar to those members who have worked in the same direction, who must kindly bear in mind in this connection that the author does not profess to put forward anything new, but merely to bring up for discussion some working notes on the subject.

In the following pages, then, the general ideas underlying the equipment and operation of polyphase substations are first dealt with, and this is followed by some features of working, and a comparison of the different types of machinery that can be employed for the work under consideration, together with some details and examples taken from actual practice. It is always to be understood that the author has in mind the case in which very large amounts of power (transmitted at high pressures) have to be handled—the modern case in fact. Moreover, on account of their greater commercial importance, three-phase systems are more particularly considered.

1. Substation Equipments for Lighting or Traction.

Considering the general case, applicable to large towns, the polyphase current will be sent over the transmission lines from the distant power-station, usually arriving at the various substations in the supply area at a pressure between 5,000 to 10,000 volts between lines, according to the length of the feeders and amount of power to be transmitted; the work to be done comprises the conversion of the whole of the current in question into direct current at 2×220 volts for lighting, or 500 to 550 volts for traction, together with the provision of means for regulating the current and feeding it into the low-pressure networks comprised in the area. It can be done by three different types of substation, each type

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By A. C. EBORALL, Member.

Polyphase systems of generation and transmission, combined with direct-current distribution from substations, are very much in evidence at the present time, in connection

with many large lighting and traction schemes, and there is little doubt but that the use of such combined systems will greatly extend in the future for those cases where power has to be supplied in very large amounts over large areas. The author thought, therefore, that a paper embodying some notes on the subject might be of interest to many members of the Institution; and, complying with a request of the President, the scope of the paper has been confined as far as possible to practical questions of everyday working that have come within his own experience. Consequently, many of the points discussed must be quite familiar to those members who have worked in the same direction, who must kindly bear in mind in this connection that the author does not profess to put forward anything new, but merely to bring up for discussion some working notes on the subject.

In the following pages, then, the general ideas underlying the equipment and operation of polyphase substations are first dealt with, and this is followed by some features of working, and a comparison of the different types of machinery that can be employed for the work under consideration, together with some details and examples taken from actual practice. It is always to be understood that the author has in mind the case in which very large amounts of power (transmitted at high pressures) have to be handled—the modern case in fact. Moreover, on account of their greater commercial importance, three-phase systems are more particularly considered.

I. Substation Equipments for Lighting or Traction.

Considering the general case, applicable to large towns, the polyphase current will be sent over the transmission lines from the distant power-station, usually arriving at the various substations in the supply area at a pressure between 5,000 to 10,000 volts between lines, according to the length of the feeders and amount of power to be transmitted; the work to be done comprises the conversion of the whole of the current in question into direct current at 2 × 220 volts for lighting, or 500 to 550 volts for traction, together with the provision of means for regulating the current and feeding it into the low-pressure networks comprised in the area. It can be done by three different types of substation, each type

embodying a distinct class of equipment, as set out more particularly below; the size of the units in the substations will vary in general between 300 and 1,000 kilowatts individual output.

(*a*) Asynchronous Motor-generator Equipment.

This type of substation equipment consists in the employment of a number of polyphase induction motors driving an equivalent number of direct-current generators; the motor-generator units will be of such a size that the high-pressure current can be led directly into the motors, and consequently the equipment and operation of the substation will be of the simplest possible character. No starting gear has to be provided beyond a simple rotor resistance for each motor, there is no synchronising to be done, and the regulation on the direct-current side is made on the fields of the generators, either by hand or by compound windings in the usual way.

The author does not know of a single case in which polyphase motors of large size (either synchronous or asynchronous) are operated with transformed current. The construction of such motors lends itself so well to high insulation of the stator that motors as small as 150 H.P. can be perfectly satisfactorily (and cheaply) built for pressures of 5,000–6,000 volts. With the large units required for substation work, it does not pay from either the technical or commercial point of view to employ step-down transformers—at any rate up to 10,000 volts. If the motors are less than about 500 H.P. individual output, and the pressure greater than this figure, it may pay to employ transformers, because the amount of slot insulation required will probably be found to be excessive, necessitating the employment of motors of large dimensions compared with their output.

The trouble with high-pressure working without transformers in the substations is as a rule in the switch-gear for the motors, but great improvements have been made in this during recent years, and at the present time there is very little to fear in this respect.

With the high-pressure current led directly into the motors, the best arrangement for the substation will usually consist in employing starting switch-pillars for the motors, these standing close against them, the direct-current board being away against a wall. The rotor resistance and stator starting switch would be interlocked, and thus, as each switch-pillar is self-contained, the starting up of each set is performed by one movement of a hand-wheel, this taking the place of the engine stop-valve in a steam plant. The

employment of a starting switch-pillar adjacent to the motor possesses the great advantage of reducing the length of the heavy rotor cables to a minimum (an important point), while security of working is assisted by interlocking the starting gear.

Of course, if the motors are provided with permanently short-circuited rotors, an auto-transformer device in the stator takes the place of the rotor resistance ; this feature of construction and method of working is not advisable however, being, for work of the character in question, far inferior to that referred to above. It should be borne in mind, in this connection, that it is standard practice nowadays to build all induction motors of large size (having wound-rotors and slip-rings), with an arrangement for short circuiting the rings and lifting up the brushes after once the motor has attained full speed, thus limiting wear (and loss) on the rings to the period of starting up—30 seconds as a usual maximum figure.

If direct current is available at the substation, being derived from a motor generator already running, or from another substation, it is perfectly possible to start up the sets as they are wanted, from the direct-current side. Under certain circumstances, this method of operation will give good results, but in general it is not so convenient as that first described, and consequently rarely used. In any case it is necessary for one or more units in the substation to be provided with rotor resistances or equivalent devices, so that they may be started from the alternating-current side whenever this may be necessary.

For feeding three-wire systems, each motor would drive two direct-current machines each of half its output, one at each end of the shaft, the two machines being in series ; or the motor would drive a single generator of the same capacity, feeding the outers, auxiliary devices being used in the usual way for balancing the load.

(*b*) Synchronous Motor-generator Equipment.

With this equipment, synchronous polyphase motors operated at the line pressure take the place of the induction motors referred to above ; conforming with standard practice, the synchronous motors would be of the revolving field type, the exciting current being led into the field system by means of slip-rings and brushes. A substation

with such an equipment will also be of a very simple character, but not quite so simple as the foregoing; this is on account of the necessity for synchronising the motors before switching them in, because the starting arrangements are more elaborate, and also because the synchronous motors are not self-exciting. The excitation of the motors would usually be effected from direct-coupled exciters, or from separate (induction) motor-driven exciting sets fed by step-down transformers, or from the bus-bars; frequently the latter method, in conjunction with either of the former methods, will prove to be the most convenient. The performance of synchronous motors depends so much upon the field adjustment (see later remarks), that a well-designed field regulator for each motor is a necessity.

The starting of the motor generator sets may be effected in several ways. By far the best way from every point of view is to start them from the direct-current side, the direct current being derived from the bus-bars, if other machines (or substations) are running, or from a small auxiliary direct-current generator driven by a low-pressure induction motor, if no direct current is available at the switchboard. Of course, as soon as the first machine is running, all the others can be started from it, but it must be remembered that it is always necessary to provide means for starting up any motor generator in the substation, from the alternating-current side, either directly or indirectly. One of the best possible adaptations of the above arrangement is to provide an auxiliary (asynchronous) motor generator which can be used for exciting and starting the main units when required; this auxiliary set would be shut down as soon as one or more of the main units is in operation, direct current thus being available at the bus-bars. If the low-pressure network is arranged to be partly fed, or balanced, by accumulators, the starting and exciting would naturally be effected initially from these, and the whole arrangement becomes one of great simplicity; this is, however, not the general case.

The operation of switching in a synchronous motor generator started in this way is of course very simple. The set being brought up to approximately synchronous speed and excited to the right value, the correct speed (as indicated by the synchronising lamps) is attained by regulating the fields of the direct-current machine now running as a

shunt-motor with all main resistance out. At the right moment, the main high-pressure switch is closed, and after this the direct-current main resistance perhaps short-circuited. Finally, the fields of both motor and generator are adjusted, the latter in order to take up the load, and the former in order to regulate the idle current of the synchronous motor.

Assuming that no direct current is available, the next best method of starting up the motor generator sets, together with their direct-coupled exciters, is by means of starting motors. On a bracket at that side of the motor generator remote from the exciter, an induction motor is placed, the rotor being mounted directly upon the extended shaft; this motor would be fed from a step-down transformer and would have a capacity of about 10 per cent. of the full load output of the main unit. The number of poles on the starting motor would be fewer than the number of field poles on the synchronous motor, being such that it can bring up the set to a speed somewhat higher than that corresponding to synchronism, in spite of the load on it due to the iron losses and excitation of the main unit, and the friction and ventilation losses of the combination. Moreover, the starting torque of this auxiliary motor must be high, it being preferably attained by the employment of a non-inductive rotor resistance; this latter is also of value when synchronising, although not absolutely necessary.

To start up then, all that has to be done is, firstly, to speed up the combination by switching in the starting motor, and cutting out the rotor resistance until the combination is at maximum speed: secondly, close the field circuit of the synchronous motor, and regulate the exciting current to get the correct pressure; thirdly, reduce the speed by slowly adjusting the rotor resistance, until the synchronising lamps indicate exact synchronism; then switch the synchronous motor on the line, and afterwards cut out the starting motor and adjust both field systems as before.

If the starting motor is constructed with a permanently short-circuited rotor (conforming to American practice), the rotor windings being of comparatively high resistance and the stator fields very strong (in order to get the necessary starting torque), then the third operation above will consist in switching out the starting motor altogether, as soon as

the correct value of field current has been attained. The speed of the combination will of course immediately drop, and the main switches must be closed as the speed passes synchronism, as shown by the pulsations on the lamps. Naturally, the operation of putting the motor on the line cannot be so well done under these circumstances, and hence, as stated above, if a starting motor has to be used at all, it is better to use a rotor resistance in conjunction with it. It may be mentioned, however, in this connection, that if the generating sets in the power-station and the synchronous motors in the substation are well designed, and particularly if the latter machines are fitted with damping coils, the synchronous motors will pull themselves into step without doing any harm, if they are switched in at approximately synchronous speed, and consequently careful adjustment may be omitted, in cases of necessity. But careful adjustment is always advisable, particularly if the motor is thrown in parallel with a number of machines already running, or if the power-station is lightly loaded, for the efforts made by the incoming machine to pull itself into exact synchronism may start the other motors hunting.

The third method of starting up a synchronous combination is referred to more particularly below, in connection with rotary converters; it consists in starting up from the alternating-current side by opening the field circuit of the synchronous motor, and then connecting the armature directly or indirectly to the line. The necessary torque is produced by the hysteresis drag, helped by eddy currents circulating in the pole-pieces or damping-coils, and is consequently small; the method has nothing to recommend it, although frequently used, and, moreover, a little consideration will show that its employment implies a motor of low efficiency at full load, as otherwise the above-mentioned losses in conjunction with the armature currents would not be great enough to get the necessary torque.

Apart from the question of power-factor, the running performance of synchronous motor generators is very similar to that of asynchronous machines, and, moreover, under proper conditions of supply, they are equally reliable.

(*c*) Rotary Converter Equipment.

Substations equipped with rotary converters are of a far more complicated character than either of the types

previously discussed, due to the special character of the machines and regulating devices. Although the rotary converter possesses similar characteristics to those of the synchronous motor, and also to those of the direct-current machine, yet it possesses in addition a number of special features having a large influence on its performance, the result being that even when such machines are working under the very best conditions, they cannot compare, with regard to simplicity of operation, with either asynchronous or synchronous motor generators.

The first point to be noted in connection with the equipment of a rotary converter substation is that the rotaries require to be operated at low pressure. The pressure between any two slip-rings, whatever the nature of the armature winding, is always a definite percentage of that on the direct-current side with a given pole-width, being about 61 per cent. for three-phase and about 71 per cent. for two-phase rotaries,[1]—consequently step-down transformers have always to be inserted between the slip-rings of the converters and the high-pressure feeders. For the large capacity units under consideration, separate transformers are always used for each phase of the transmission line; but it may be noted here that, for small three-phase or six-phase rotaries (up to about 100 kilowatts capacity) it is always preferable to use three-phase transformers for the purpose, for, owing to their common magnetic circuit, possible pressure variation between the phases of the three-phase transmission becomes reduced in amount, as such transformers form excellent balancers.

In two-phase work, there will be two transformers per rotary; in three-phase or six-phase work of the character under consideration, there will be three. The manner in which these transformers are connected up in the two latter cases is of importance, and therefore a brief reference may be made to it here. Considering first the three-phase case, it may be stated at once that as a rule, the best arrangement of the three transformers will be to connect them up in a "mesh," on both high- and low-pressure sides. This is principally because in the event of one transformer develop-

[1] These are the no-load values—when the machine is loaded, they are naturally departed from to a small extent, on account of the armature drop. Moreover, if the impressed pressure-wave is not sinusoidal, the values given will be departed from.

ing a fault and blowing its fuse, the supply need not be interrupted for a moment, for the remaining two will continue to supply a three-phase current to all three phases of the rotary; the reactions in the latter tend to keep the arrangement symmetrical, and the phases equally balanced. Under these circumstances the rotary can be kept fully loaded over the period of emergency, if not too long—naturally the increase of heating in the two transformers doing all the work must be carefully watched. If the transmers had been "star" connected, single-phase current would be delivered under the same circumstances, and the rotary would have to be immediately cut out on account of the heavy sparking that would occur at the commutator; even supposing sparking to be absent, the machine would not be able to carry anything like its full load over the period of emergency, and moreover the system would be thrown greatly out of balance. Another advantage (of secondary importance) with mesh-connected transformers is that the secondaries are cheaper to wind, because the area of the copper in the winding is 58 per cent. of the copper area for the corresponding "star"-connected transformer.

One advantage of the star connection lies in the fact that the space taken up by the primary winding of each transformer is somewhat less in comparison, because the pressure across each transformer is only 58 per cent. of the full line pressure, and hence winding space is saved, on account of the reduction in the insulation. This is, of course, an advantage, especially when dealing with pressures of the order of 10,000 volts, but, in the author's opinion, it is one not to be compared with the safeguard against total breakdown afforded by the mesh connection.

Exactly the same arguments apply to the six-phase case, in which the secondaries of the transformers are arranged with either a double mesh or a double star connection, but preferably the former, as indicated diagrammatically in Fig. 1.

It will be seen that this connection makes use of two distinct mesh connections, one superposed upon the other, the two meshes being in electrical connection through the armature windings of the converter. It is obtained from three single-phase transformers, similar in all respects, each being wound with two equal secondary windings.

The three secondary windings *a, b, c,* are mesh connected,

and led to three slip-rings in connection with the armature winding of the rotary at points 120 (electrical) degrees apart, while the three secondaries *d*, *e*, and *f*, are also mesh connected, but in the opposite direction ; the three conductors from the points of this mesh are taken to the remaining three slip-rings on the shaft of the rotary, which are in con-

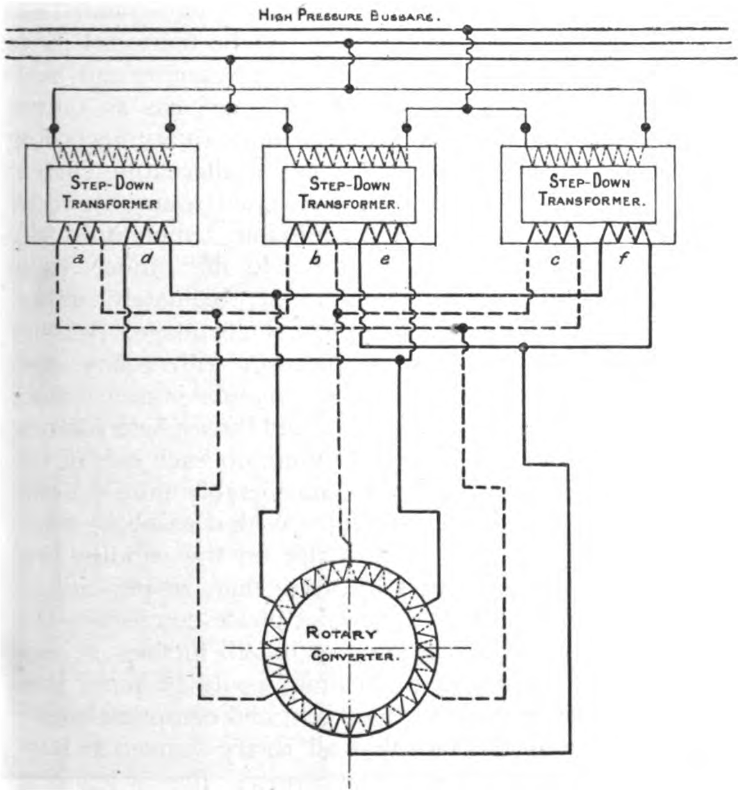

Fig. 1.—Six-Phase Mesh Connection for Rotary Converters.

nection with points on the armature winding 120 (electrical) degrees apart, and lying midway between the tappings to the three slip-rings first mentioned. A little consideration will show that, under these circumstances and because one half of the secondary of each transformer is cross-connected relatively to the other half (the two halves differing therefore 180 degrees in phase) the two meshes differ half a cycle

(180 degrees) from one another, and consequently satisfy the six-phase condition.

While the six-phase connection for rotary converters is more complicated and somewhat more expensive than the three-phase, yet it will undoubtedly pay to use it; as a matter of fact, it is somewhat surprising that the merits of this form of connection do not appear to be generally recognised, for Steinmetz and Kapp long ago pointed out that the output of any given rotary can be increased 40–50 per cent. by its use—that is to say, for the same mean heating of the armature coils, a six-phase rotary has an output 40–50 per cent. greater than the three-phase rotary, according to the value of the power-factor of the alternating-current side. As the output of any well-designed rotary converter is determined solely by the permissible temperature rise (there being no distortion of the field flux under usual working conditions—power-factor approximately unity), this increased output is a great practical advantage. Another advantage of the six-phase connection with rotary converters is that the heating of the armature is much more uniform—as is well known, in two- and three-phase rotaries, those portions of the armature winding on each side of the tappings to the slip-rings heat up considerably more than the remaining portions of the winding. With a six-phase winding, the maximum temperature rise on the winding will rarely exceed the minimum by more than 20 per cent.

It is not probable that the twelve-phase connection will take a place in practice, for the gain in still further increase of output and uniformity of heating would be more than counterbalanced by the increased cost and complication.

On account of the fact that all rotary converters have to be fed from step-down transformers, the switch-gear becomes more extensive, for although as a rule not necessary, it is good practice to provide switches in the secondary circuits of the transformers. There is, however, one case where such switches are absolutely necessary, and that is for two-phase rotaries arranged for starting from the direct-current side; in this case, unless the transformer secondaries are open, they become short-circuited (at the moment of starting) upon the armature winding, causing a great increase in starting current, and violent sparking at the commutator, until the machine is well towards full

speed. The heavy current switches in the secondary circuits are best mounted upon, or close to the transformers, which latter should be close up to the rotaries, in order to reduce to a minimum the pressure drop, losses, and cost, of the heavy conductors.

Before leaving the subject of the transformer connections

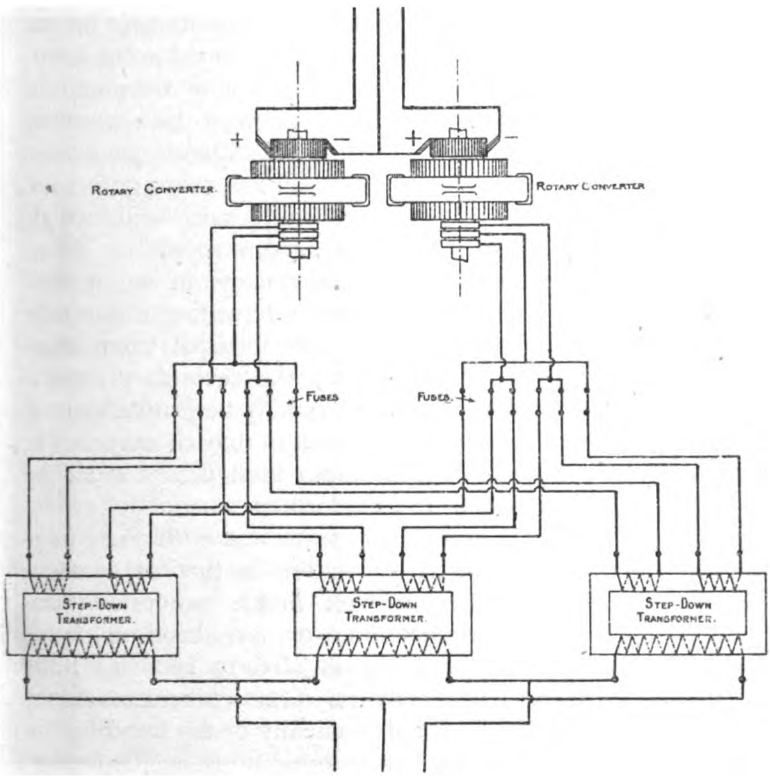

Fig. 2.—Connections for Rotary Converters in Parallel Feeding Three-wire System.

for three-phase rotary converters, it may be mentioned that a case sometimes arises in practice in which a special transformer arrangement is necessary. When two or more rotaries are not arranged to be fed (for any special reason) from separate groups of transformers on the alternating-current side, and they are connected to a three-wire network on the direct-current side, then it is necessary to wind each

unit forming the group of (two or three) transformers feeding the rotaries with a multiple secondary winding, as described above, the arrangement being as shown in Fig. 2, illustrating the connections for two machines. That is to say, it is impossible to operate a number of rotaries feeding a three-wire network from common bus-bars on the alternating-current side. The reason is readily apparent from the figure—the slip-ring sides of the machines cannot be *directly* paralleled, owing to the connection already existing on the direct-current side—if they were directly joined a disastrous short-circuit would naturally result. It may be noted in passing that the arrangement of the fuses in the secondary circuits of the transformers shown in this figure [1] (each conductor coming from a slip-ring is fused twice) is a good one, for if one transformer gives out, the service will not be interrupted, for the reason already given above.

There is, however, a certain advantage in using *star-connected* transformers for converters feeding three-wire systems, for by the adoption of this form of connection better balancing can be attained; the secondary neutral points of each group of transformers may be profitably connected to the middle wire, which latter may or may not be earthed. Under these circumstances each rotary would be fed from a separate group of transformers.

The next question arising in connection with the equipment of a rotary converter substation is that of pressure regulation. It is clear that with motor generator substations (whether asynchronous or synchronous), this question hardly comes in, for, as already indicated, the regulation is performed wholly on direct-current machines of standard design, either automatically or by hand, in the simplest possible manner. The conditions are, however, quite different with rotary converters, because the pressure on either side is practically totally independent of the field strength (although not of the field configuration), and consequently, the direct-current pressure cannot be varied by regulation on the fields alone.

There are two commercial ways of regulating rotary converters, each depending upon the same principle, namely, that of altering the pressure on the slip-rings in order to get

[1] This arrangement of fuses for such a case originated with the General Electric Company (U.S.A.).

a corresponding alteration on the direct-current side; as already pointed out, the ratio of the two pressures is practically a constant. The first method consists in varying by hand the impressed pressure on the slip-rings, and can be employed in two ways—either the impressed pressure can be altered by altering the ratio of transformation of the step-down transformers, or it can be altered by means of an "induction regulator." In the first case, the step-down transformers are so arranged in conjunction with a multiple contact switch that either the number of secondary turns, or the number of primary turns, can be altered by hand, thus altering the ratio of transformation; the transformers supplying each rotary have their regulating switches interlocked, so that the turns are cut in or out simultaneously. It is obvious that this method has several disadvantages, the most serious being those of first cost, and difficulty of operation. If the regulation is performed on the primaries, the switches become somewhat difficult and expensive to construct properly, on account of the high pressure of the circuits into which they are connected, while if the regulation is performed on the secondary sides, the expense becomes even greater, on account of the heavy currents to be handled, while the difficulties that arise with the contact surfaces of all regulating switches for heavy currents are well known. But in addition there is the difficulty of arranging such switches to regulate gradually, and to avoid short-circuiting the sections of the transformer winding connected to the contacts of the regulator, as these sections are being cut out or in. Consequently the employment of an induction regulator which does not suffer from any of the above-mentioned defects, and which has but small losses as a rule, will give the best results if hand regulation of the rotaries is asked for or desired.

On account of difficulties connected with insulation, induction regulators should be connected into the secondary circuits of the step-down transformers. As usually constructed, such regulators consist of an iron core arranged in connection with a shunt and series winding in each phase in such a manner, that a movement of the core will decrease or increase the mutual induction between the two windings. Thus if the core is moved inwards, the pressure on the converter slip-rings is reduced, on account of the inductive

action of the shunt winding on the series winding, while as the core is moved outwards, the effect of the shunt coils on the series coils becomes less and less, until at the end of the travel of the core, the pressure on the slip-rings is practically the full pressure of the transformer secondaries. Such an apparatus is easy and cheap to construct, and very effective in operation, a range of six per cent., up or down, being easily attained; moreover, it can be readily arranged to be operated from a distance, and having no contacts or moving conductors, is unlikely to get out of order.

A modification of the induction regulator, first devised, the author believes, by Mr. M. B. Field, is shown in Fig. 3; it possesses the advantage of being somewhat more efficient than the induction regulator described above. The secondary of each step-down transformer has an extension in the form of some extra turns capable of carrying about 25 per cent. of the full secondary current; these extra turns are connected to a small regulating switch, and to the windings of smaller section of a small auxiliary transformer (with ratio say 1 : 4) as shown. The secondary of the auxiliary transformer is in series with the low pressure circuit, and adds or subtracts a small E.M.F. to this circuit as desired. It will be seen that both the voltage and current can be very readily handled, without undue expense, and, moreover, the supply is not interrupted should the regulating switch get out of order.

The second method of varying the impressed pressure on the slip rings of the rotary, in order to get the desired direct current pressure, is of considerable technical interest. Briefly, it consists in compounding the rotaries, and providing a certain amount of self-induction between the terminals of the transformer secondaries and the slip-rings of the machines, if not already existing, by inserting choking coils in the various leads. The rotary converters, being synchronous machines, operate at a power-factor determined wholly by the field excitation; for an alteration of the latter with a given load on the machines, increases or decreases the power-factor of the alternating current circuits; for each load on the rotary, there is, of course, a certain excitation that will make the power-factor a maximum, in accordance with the well-known "V" curve. Let now the shunt winding on the fields of a rotary converter, arranged

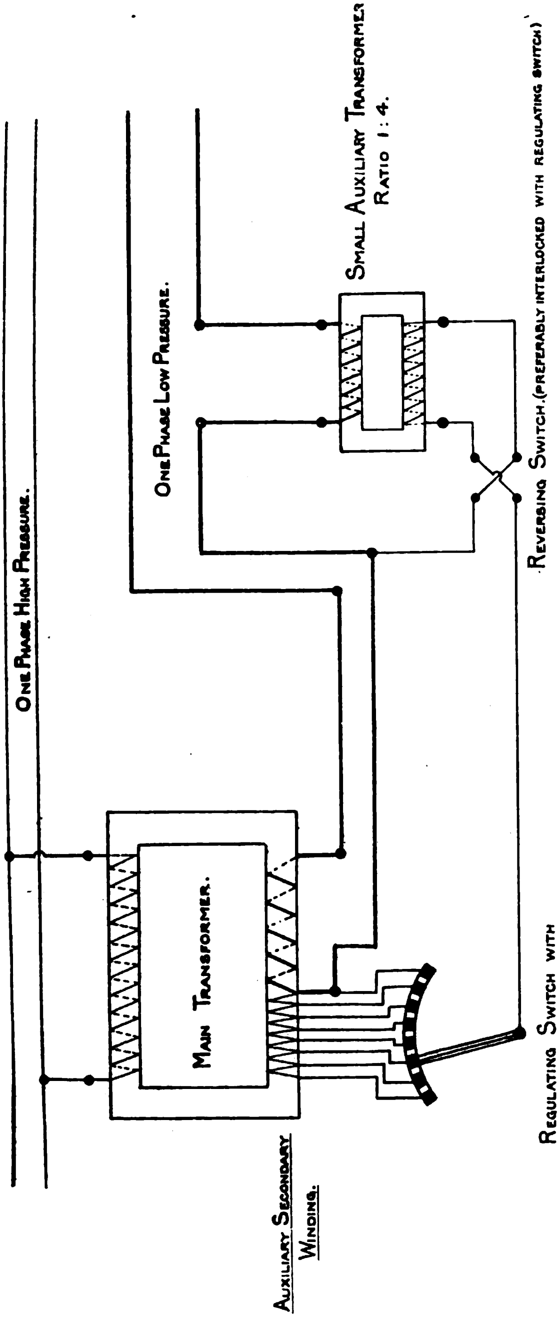

Fig. 3.—Diagram of Connections for One Form of Induction Regulator.

with compound winding, and, if necessary, with small choking coils, be so adjusted that when operating at no load, the machine takes a certain amount of lagging current, say 30–40 per cent. of the full-load current, partly due to the under-excitation, partly due to the reactance in each phase. As the load comes on, the field flux increases, on account of the current in the series winding—that is, the lagging current diminishes, and therefore the impressed pressure increases, producing a corresponding rise in the direct current pressure; this strengthens the fields still more (on account of the shunt winding), until a balance between the two pressures is attained. At full load, the field flux is at its working maximum; the input current will be by this time leading, due to the over-excitation having wiped out the lag produced by the reactance, and the direct current pressure will be raised to the correct value, on account of the increased pressure on the slip-rings. By suitable proportions of the reactance and field windings, excellent pressure regulation can be attained in this way, in a perfectly automatic manner; it is perfectly easy to arrange for the direct current pressure to be over-compounded 10–15 per cent., the actual regulation being nearly as good as with an ordinary over-compounded direct current machine,[1] provided the pressure at the ends of the feeders in the substations is maintained as nearly as possible constant. The only objection to this method of regulation is the influence it has upon the regulation at the feeding points—that is, at the high pressure bus-bars in the sub-stations, for with a number of the latter in parallel, the variation of the power-factor naturally means that the attainment of constant pressure at the ends of the feeders becomes a difficult matter.

The extent to which over-compounding of rotaries can be carried—by means of the above described method—depends mostly upon the rating of the machine with regard to the work it has to do. The limit is of course reached when the current running into the rotary is made to lead (by increasing the exciting current) the impressed pressure by

[1] With a rotary converter of standard design, the change of field flux necessary in order to get the desired amount of over-compounding is much greater than is required with the equivalent direct current machine, for the direct current pressure is not proportional to the field flux but proportional to the impressed pressure on the slip-rings.

90°, for then the inductive E.M.F. of the choking coil (which is 90° behind the current) is in phase with the impressed pressure, and consequently boosts it by that amount; if the current lags behind the impressed pressure by 90°, the inductive E.M.F. of the coil is half a cycle behind the impressed pressure, and diminishes the latter to a value given by subtracting the inductive E.M.F. of the choking coil from the impressed pressure. Neither of these limits are found in practice, for if the angle or lag or lead exceeds certain well-defined values (depending upon the shape of the "V" curve—that is, upon the armature reaction of the machine), the rotary will naturally not carry its rated load. The more liberally rated is the converter, the greater is the range of regulation attained; if the amount of over-compounding required is large (say 15–25 per cent.), the rotary must be chosen large for the work it has to do, although not in this proportion.

Compound wound rotary converters are connected and paralleled on the direct current sides in precisely the same manner as similar direct current machines, equalising bus-bars and switches being used, and therefore the same precautions have to be taken with them should accumulators be used in parallel with the low-pressure feeders.

From what has been said above, it will readily be seen that of the two good methods put forward for regulating the pressure on the direct current sides of the machines, that best adapted for the requirements of lighting work is given by the employment of induction regulators, allowing the pressure to be gradually varied by hand in accordance with the slowly varying load; for traction work, the employment of compound windings (that is, regulation by lagging and leading currents) is preferable on account of the large range of regulation required, and the rapid variations of the load. In some special cases, however, the combination of the two methods will give very good results.

With regard to the starting of rotary converters, all the remarks already made regarding the starting of synchronous motor generators are applicable, as the only difference in this respect between the two classes of machine is that rotary converters are invariably arranged to be self-exciting from their direct current sides. Wherever possible then, such machines should be arranged to be started from the

direct current side, either from the bus-bars, or from an auxiliary asynchronous motor generator. As in the other case, this latter indirect method of starting is far preferable to any other, if no direct current is available at the switchboard.

The next best method to this is that given by induction motors directly coupled to the shafts of the rotaries, while the fourth and last method available (briefly noticed already in connection with the starting of synchronous motors) simply consists in switching the machine directly on the high-pressure lines. As this method has been put forward in connection with several important British schemes, and is in use in more than one of them at the present time, it may not be out of place to devote a few words in its consideration, although in general the method is objectionable.

Any modern synchronous polyphase motor can be started up without difficulty from the high-pressure lines, no matter how constructed; that is, whether the field poles be solid or laminated, whether provided with damping coils or not, &c.—it is only a matter of sufficient starting-current and good mechanical design. This method of starting, as used in connection with rotary converter plants, is as follows: The direct current main and field-switches are opened, only a volt-meter being left across the direct current side, and then the line-current is switched on the slip-rings, either at full or reduced pressure, this latter being arranged for by an alteration in the number of secondary turns on the step-down transformers. Owing partly to the eddy currents in the pole pieces, metal cheeks of field-bobbins, damping coils (where these are used), but principally to the hysteresis lag in the pole pieces, the rotary immediately starts, and is very soon up to synchronous speed. The volt-meter (already referred to) on the direct current side indicates nothing at the moment of starting beyond very feeble oscillations of the pointer, for the current traversing its coils is of course alternating; but as the rotary increases its speed the pointer begins to move backwards and forwards over the scale, its movements corresponding to the rapidly diminishing frequency of the pressure at the direct current terminals; when synchronous speed has been reached the volt-meter pointer will again be

steady, for the current through it is now a direct current. The proper time for putting on the field-current is just before synchronism is reached, and is indicated by the volt-meter; when the beats of the pointer are slowest, that is, just below synchronous speed, when the pointer is moving slowly from side to side over the scale, the field-current can be put in. But it may be noted here that it makes all the difference at which side of the scale the pointer is when the field-circuit is closed; one side is right and the other wrong, depending upon individual circumstances. If the fields have been put on when the pointer is at the wrong side of the scale, then the polarity of the direct current side of the converter will be reversed; with most machines this means that the rotary must be switched out and synchronised again in order to get synchronism at the right pole. In order to make quite sure that the machine has synchronised at the right pole, it is good practice to provide a pole indicator on each direct current panel, so that after the excitation has been put on, the polarity of the direct current side can be checked before the rotary is connected to the direct current bus-bars. Needless to say, a lamp can be substituted for the volt-meter mentioned above across the direct current terminals—it will be bright at the first moments of starting, and also when the neighbourhood of synchronous speed is reached, while between these limits the light will pulsate, and the excitation should be put on when the light is pulsating slowly, the lamp being either bright or dark, according to circumstances.

It will be readily understood that the above remarks regarding the right time to put on the excitation in order to get the right polarity are only applicable to the case of self-exciting machines; if the machines are bus excited, which is very seldom, the converter will pull itself round under protest to the correct polarity with a great rush of current, no matter at which pole the machine has synchronised. A point worthy of note is that even without the exciting current the rotary will come up to absolute synchronous speed, for there is no induction motor action with the rotary converter or synchronous motor. A rotary converter can operate without field excitation, by reason of the heavy lagging currents that would run through its

armature windings under these circumstances; these wattless currents magnetise the fields to the extent necessary to produce the balancing back E.M.F. of the armature. However, such a method of operation cannot be commercial, for the machines would not carry their rated load; the heavy lagging currents would overload the mains and destroy the pressure regulation of both sides of the system, and the rotaries would spark and hunt. Up to the present, the author has not made any tests on the operation of large rotaries without field excitation, for there is generally little time for such experiments when putting down plant, and, moreover, they may turn out to be somewhat costly; it is an interesting question, however, and it would be of value to know from those who have actually made tests on large units under commercial conditions whether the objections given above are as real as they appear to be. Perhaps with machines having high armature reaction (small air-gaps, &c.) the full load could be carried without the machine stopping, but its performance under these circumstances could hardly be otherwise than poor, quite apart from the bad effect produced on the system; moreover, rotaries with considerable armature reaction have a greater tendency to hunt than those with very stiff fields.

When starting a converter in the manner above described, it is necessary to take certain precautions until synchronism is attained; the series field-windings must be open as well as the shunt, and these latter windings must be opened in five or six places. Otherwise they would break down, due to the large E.M.F. (many thousand volts) induced in them by the alternating flux of the armature. Also, as the starting current will never be less than twice the full-load current, even if damping-coils are used, and will frequently be of the order of three or four times the full-load current, it is necessary to make arrangements for short-circuiting the amperemeters and fuses, otherwise they would be damaged by the overload.

The great objections to the above described method of starting are of course the large starting-current required, and the risk of getting the wrong polarity; the former will wholly upset the pressure regulation of the system, partly on account of its magnitude, but principally because of its low power-factor, while the latter might cause an

accident, and in any case would cause time to be lost when adding a machine to the circuit. For lighting work the employment of this method is absolutely out of the question.

II.—Some Features of Working.

With regard to asynchronous motor generator sub-stations there is practically nothing to be said, on account of the simple character of the equipment and its operation. Two points must be kept in mind however—the sets must be run as fully loaded as possible, and the motor air-gaps must be watched. As the power-factor of the motors will be less than 90 per cent. below three-quarter load, running the machines well loaded becomes even of greater importance than with other classes of electrical machinery, in order to avoid heavy, lagging currents in the feeders. As a matter of fact, it is a good thing to overload such motor-generators (in moderation) before adding a machine to the bus-bars, for then a high power-factor over a wide range of load is assured ; the risk is very small, on account of the rapidity with which another set can be started up and put on the circuit. The other point just mentioned—relative to the air-gaps—is of some importance on account of the small clearance in the motors. As with all induction motors, the air-gap length is determined wholly by mechanical considerations, being made as small as possible in order to get high power-factors, it becomes necessary to check it from time to time, in order to make sure that the gap at the bottom has not decreased to a dangerous extent. With large induction motors the gap (iron to iron) will be originally about $\frac{1}{450}$ of the rotor diameter—a 200 B.H.P. motor would thus have a clearance of 0·1 inch with a rotor diameter of $3\frac{3}{4}$ feet, so it will be seen that no considerable diminution of this length can be allowed on account of the magnetic pull, even assuming exceptionally stiff shafts. The stator case of such motors should never be cast with the bed-plate, for if it is separate a thickness or two of metal foil can be inserted between the feet of the case and the bed-plate seatings, by removing which the gap at the bottom can be increased when the brasses have worn

embodying a distinct class of equipment, as set out more particularly below ; the size of the units in the substations will vary in general between 300 and 1,000 kilowatts individual output.

(*a*) Asynchronous Motor-generator Equipment.

This type of substation equipment consists in the employment of a number of polyphase induction motors driving an equivalent number of direct-current generators; the motor-generator units will be of such a size that the high-pressure current can be led directly into the motors, and consequently the equipment and operation of the substation will be of the simplest possible character. No starting gear has to be provided beyond a simple rotor resistance for each motor, there is no synchronising to be done, and the regulation on the direct-current side is made on the fields of the generators, either by hand or by compound windings in the usual way.

The author does not know of a single case in which polyphase motors of large size (either synchronous or asynchronous) are operated with transformed current. The construction of such motors lends itself so well to high insulation of the stator that motors as small as 150 H.P. can be perfectly satisfactorily (and cheaply) built for pressures of 5,000–6,000 volts. With the large units required for substation work, it does not pay from either the technical or commercial point of view to employ step-down transformers—at any rate up to 10,000 volts. If the motors are less than about 500 H.P. individual output, and the pressure greater than this figure, it may pay to employ transformers, because the amount of slot insulation required will probably be found to be excessive, necessitating the employment of motors of large dimensions compared with their output.

The trouble with high-pressure working without transformers in the substations is as a rule in the switch-gear for the motors, but great improvements have been made in this during recent years, and at the present time there is very little to fear in this respect.

With the high-pressure current led directly into the motors, the best arrangement for the substation will usually consist in employing starting switch-pillars for the motors, these standing close against them, the direct-current board being away against a wall. The rotor resistance and stator starting switch would be interlocked, and thus, as each switch-pillar is self-contained, the starting up of each set is performed by one movement of a hand-wheel, this taking the place of the engine stop-valve in a steam plant. The

employment of a starting switch-pillar adjacent to the motor possesses the great advantage of reducing the length of the heavy rotor cables to a minimum (an important point), while security of working is assisted by interlocking the starting gear.

Of course, if the motors are provided with permanently short-circuited rotors, an auto-transformer device in the stator takes the place of the rotor resistance ; this feature of construction and method of working is not advisable however, being, for work of the character in question, far inferior to that referred to above. It should be borne in mind, in this connection, that it is standard practice nowadays to build all induction motors of large size (having wound-rotors and slip-rings), with an arrangement for short circuiting the rings and lifting up the brushes after once the motor has attained full speed, thus limiting wear (and loss) on the rings to the period of starting up—30 seconds as a usual maximum figure.

If direct current is available at the substation, being derived from a motor generator already running, or from another substation, it is perfectly possible to start up the sets as they are wanted, from the direct-current side. Under certain circumstances, this method of operation will give good results, but in general it is not so convenient as that first described, and consequently rarely used. In any case it is necessary for one or more units in the substation to be provided with rotor resistances or equivalent devices, so that they may be started from the alternating-current side whenever this may be necessary.

For feeding three-wire systems, each motor would drive two direct-current machines each of half its output, one at each end of the shaft, the two machines being in series ; or the motor would drive a single generator of the same capacity, feeding the outers, auxiliary devices being used in the usual way for balancing the load.

(*b*) Synchronous Motor-generator Equipment.

With this equipment, synchronous polyphase motors operated at the line pressure take the place of the induction motors referred to above ; conforming with standard practice, the synchronous motors would be of the revolving field type, the exciting current being led into the field system by means of slip-rings and brushes. A substation

with such an equipment will also be of a very simple character, but not quite so simple as the foregoing; this is on account of the necessity for synchronising the motors before switching them in, because the starting arrangements are more elaborate, and also because the synchronous motors are not self-exciting. The excitation of the motors would usually be effected from direct-coupled exciters, or from separate (induction) motor-driven exciting sets fed by step-down transformers, or from the bus-bars; frequently the latter method, in conjunction with either of the former methods, will prove to be the most convenient. The performance of synchronous motors depends so much upon the field adjustment (see later remarks), that a well-designed field regulator for each motor is a necessity.

The starting of the motor generator sets may be effected in several ways. By far the best way from every point of view is to start them from the direct-current side, the direct current being derived from the bus-bars, if other machines (or substations) are running, or from a small auxiliary direct-current generator driven by a low-pressure induction motor, if no direct current is available at the switchboard. Of course, as soon as the first machine is running, all the others can be started from it, but it must be remembered that it is always necessary to provide means for starting up any motor generator in the substation, from the alternating-current side, either directly or indirectly. One of the best possible adaptations of the above arrangement is to provide an auxiliary (asynchronous) motor generator which can be used for exciting and starting the main units when required; this auxiliary set would be shut down as soon as one or more of the main units is in operation, direct current thus being available at the bus-bars. If the low-pressure network is arranged to be partly fed, or balanced, by accumulators, the starting and exciting would naturally be effected initially from these, and the whole arrangement becomes one of great simplicity; this is, however, not the general case.

The operation of switching in a synchronous motor generator started in this way is of course very simple. The set being brought up to approximately synchronous speed and excited to the right value, the correct speed (as indicated by the synchronising lamps) is attained by regulating the fields of the direct-current machine now running as a

shunt-motor with all main resistance out. At the right moment, the main high-pressure switch is closed, and after this the direct-current main resistance perhaps short-circuited. Finally, the fields of both motor and generator are adjusted, the latter in order to take up the load, and the former in order to regulate the idle current of the synchronous motor.

Assuming that no direct current is available, the next best method of starting up the motor generator sets, together with their direct-coupled exciters, is by means of starting motors. On a bracket at that side of the motor generator remote from the exciter, an induction motor is placed, the rotor being mounted directly upon the extended shaft; this motor would be fed from a step-down transformer and would have a capacity of about 10 per cent. of the full load output of the main unit. The number of poles on the starting motor would be fewer than the number of field poles on the synchronous motor, being such that it can bring up the set to a speed somewhat higher than that corresponding to synchronism, in spite of the load on it due to the iron losses and excitation of the main unit, and the friction and ventilation losses of the combination. Moreover, the starting torque of this auxiliary motor must be high, it being preferably attained by the employment of a non-inductive rotor resistance; this latter is also of value when synchronising, although not absolutely necessary.

To start up then, all that has to be done is, firstly, to speed up the combination by switching in the starting motor, and cutting out the rotor resistance until the combination is at maximum speed : secondly, close the field circuit of the synchronous motor, and regulate the exciting current to get the correct pressure ; thirdly, reduce the speed by slowly adjusting the rotor resistance, until the synchronising lamps indicate exact synchronism ; then switch the synchronous motor on the line, and afterwards cut out the starting motor and adjust both field systems as before.

If the starting motor is constructed with a permanently short-circuited rotor (conforming to American practice), the rotor windings being of comparatively high resistance and the stator fields very strong (in order to get the necessary starting torque), then the third operation above will consist in switching out the starting motor altogether, as soon as

the correct value of field current has been attained. The speed of the combination will of course immediately drop, and the main switches must be closed as the speed passes synchronism, as shown by the pulsations on the lamps. Naturally, the operation of putting the motor on the line cannot be so well done under these circumstances, and hence, as stated above, if a starting motor has to be used at all, it is better to use a rotor resistance in conjunction with it. It may be mentioned, however, in this connection, that if the generating sets in the power-station and the synchronous motors in the substation are well designed, and particularly if the latter machines are fitted with damping coils, the synchronous motors will pull themselves into step without doing any harm, if they are switched in at approximately synchronous speed, and consequently careful adjustment may be omitted, in cases of necessity. But careful adjustment is always advisable, particularly if the motor is thrown in parallel with a number of machines already running, or if the power-station is lightly loaded, for the efforts made by the incoming machine to pull itself into exact synchronism may start the other motors hunting.

The third method of starting up a synchronous combination is referred to more particularly below, in connection with rotary converters; it consists in starting up from the alternating-current side by opening the field circuit of the synchronous motor, and then connecting the armature directly or indirectly to the line. The necessary torque is produced by the hysteresis drag, helped by eddy currents circulating in the pole-pieces or damping-coils, and is consequently small; the method has nothing to recommend it, although frequently used, and, moreover, a little consideration will show that its employment implies a motor of low efficiency at full load, as otherwise the above-mentioned losses in conjunction with the armature currents would not be great enough to get the necessary torque.

Apart from the question of power-factor, the running performance of synchronous motor generators is very similar to that of asynchronous machines, and, moreover, under proper conditions of supply, they are equally reliable.

(*c*) Rotary Converter Equipment.

Substations equipped with rotary converters are of a far more complicated character than either of the types

previously discussed, due to the special character of the machines and regulating devices. Although the rotary converter possesses similar characteristics to those of the synchronous motor, and also to those of the direct-current machine, yet it possesses in addition a number of special features having a large influence on its performance, the result being that even when such machines are working under the very best conditions, they cannot compare, with regard to simplicity of operation, with either asynchronous or synchronous motor generators.

The first point to be noted in connection with the equipment of a rotary converter substation is that the rotaries require to be operated at low pressure. The pressure between any two slip-rings, whatever the nature of the armature winding, is always a definite percentage of that on the direct-current side with a given pole-width, being about 61 per cent. for three-phase and about 71 per cent. for two-phase rotaries,[1]—consequently step-down transformers have always to be inserted between the slip-rings of the converters and the high-pressure feeders. For the large capacity units under consideration, separate transformers are always used for each phase of the transmission line; but it may be noted here that, for small three-phase or six-phase rotaries (up to about 100 kilowatts capacity) it is always preferable to use three-phase transformers for the purpose, for, owing to their common magnetic circuit, possible pressure variation between the phases of the three-phase transmission becomes reduced in amount, as such transformers form excellent balancers.

In two-phase work, there will be two transformers per rotary; in three-phase or six-phase work of the character under consideration, there will be three. The manner in which these transformers are connected up in the two latter cases is of importance, and therefore a brief reference may be made to it here. Considering first the three-phase case, it may be stated at once that as a rule, the best arrangement of the three transformers will be to connect them up in a "mesh," on both high- and low-pressure sides. This is principally because in the event of one transformer develop-

[1] These are the no-load values—when the machine is loaded, they are naturally departed from to a small extent, on account of the armature drop. Moreover, if the impressed pressure-wave is not sinusoidal, the values given will be departed from.

ing a fault and blowing its fuse, the supply need not be interrupted for a moment, for the remaining two will continue to supply a three-phase current to all three phases of the rotary; the reactions in the latter tend to keep the arrangement symmetrical, and the phases equally balanced. Under these circumstances the rotary can be kept fully loaded over the period of emergency, if not too long—naturally the increase of heating in the two transformers doing all the work must be carefully watched. If the transmers had been "star" connected, single-phase current would be delivered under the same circumstances, and the rotary would have to be immediately cut out on account of the heavy sparking that would occur at the commutator; even supposing sparking to be absent, the machine would not be able to carry anything like its full load over the period of emergency, and moreover the system would be thrown greatly out of balance. Another advantage (of secondary importance) with mesh-connected transformers is that the secondaries are cheaper to wind, because the area of the copper in the winding is 58 per cent. of the copper area for the corresponding "star"-connected transformer.

One advantage of the star connection lies in the fact that the space taken up by the primary winding of each transformer is somewhat less in comparison, because the pressure across each transformer is only 58 per cent. of the full line pressure, and hence winding space is saved, on account of the reduction in the insulation. This is, of course, an advantage, especially when dealing with pressures of the order of 10,000 volts, but, in the author's opinion, it is one not to be compared with the safeguard against total breakdown afforded by the mesh connection.

Exactly the same arguments apply to the six-phase case, in which the secondaries of the transformers are arranged with either a double mesh or a double star connection, but preferably the former, as indicated diagrammatically in Fig. 1.

It will be seen that this connection makes use of two distinct mesh connections, one superposed upon the other, the two meshes being in electrical connection through the armature windings of the converter. It is obtained from three single-phase transformers, similar in all respects, each being wound with two equal secondary windings.

The three secondary windings *a, b, c*, are mesh connected,

and led to three slip-rings in connection with the armature winding of the rotary at points 120 (electrical) degrees apart, while the three secondaries *d*, *e*, and *f*, are also mesh connected, but in the opposite direction; the three conductors from the points of this mesh are taken to the remaining three slip-rings on the shaft of the rotary, which are in con-

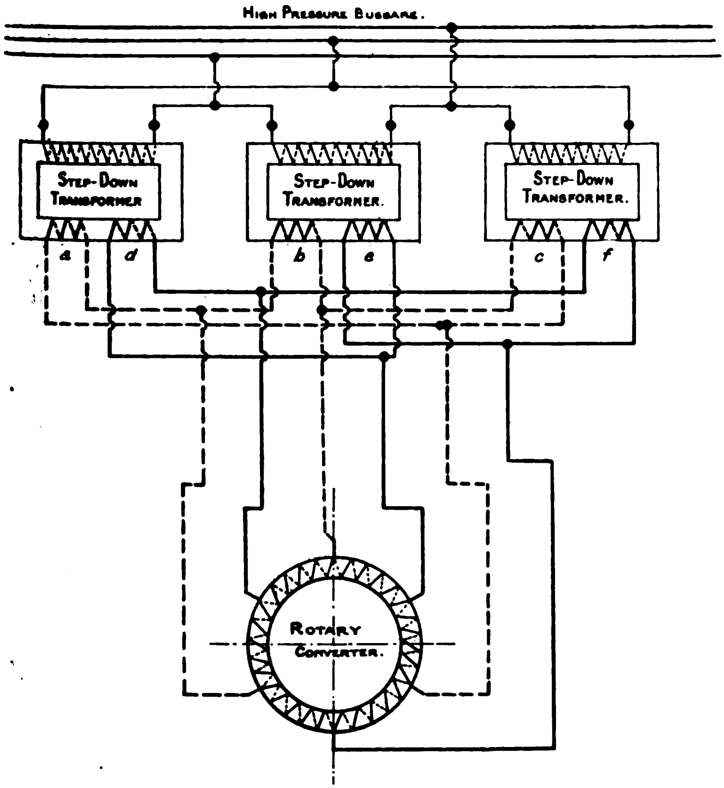

Fig. 1.—Six-Phase Mesh Connection for Rotary Converters.

nection with points on the armature winding 120 (electrical) degrees apart, and lying midway between the tappings to the three slip-rings first mentioned. A little consideration will show that, under these circumstances and because one half of the secondary of each transformer is cross-connected relatively to the other half (the two halves differing therefore 180 degrees in phase) the two meshes differ half a cycle

(180 degrees) from one another, and consequently satisfy the six-phase condition.

While the six-phase connection for rotary converters is more complicated and somewhat more expensive than the three-phase, yet it will undoubtedly pay to use it; as a matter of fact, it is somewhat surprising that the merits of this form of connection do not appear to be generally recognised, for Steinmetz and Kapp long ago pointed out that the output of any given rotary can be increased 40–50 per cent. by its use—that is to say, for the same mean heating of the armature coils, a six-phase rotary has an output 40–50 per cent. greater than the three-phase rotary, according to the value of the power-factor of the alternating-current side. As the output of any well-designed rotary converter is determined solely by the permissible temperature rise (there being no distortion of the field flux under usual working conditions—power-factor approximately unity), this increased output is a great practical advantage. Another advantage of the six-phase connection with rotary converters is that the heating of the armature is much more uniform—as is well known, in two- and three-phase rotaries, those portions of the armature winding on each side of the tappings to the slip-rings heat up considerably more than the remaining portions of the winding. With a six-phase winding, the maximum temperature rise on the winding will rarely exceed the minimum by more than 20 per cent.

It is not probable that the twelve-phase connection will take a place in practice, for the gain in still further increase of output and uniformity of heating would be more than counterbalanced by the increased cost and complication.

On account of the fact that all rotary converters have to be fed from step-down transformers, the switch-gear becomes more extensive, for although as a rule not necessary, it is good practice to provide switches in the secondary circuits of the transformers. There is, however, one case where such switches are absolutely necessary, and that is for two-phase rotaries arranged for starting from the direct-current side; in this case, unless the transformer secondaries are open, they become short-circuited (at the moment of starting) upon the armature winding, causing a great increase in starting current, and violent sparking at the commutator, until the machine is well towards full

speed. The heavy current switches in the secondary circuits are best mounted upon, or close to the transformers, which latter should be close up to the rotaries, in order to reduce to a minimum the pressure drop, losses, and cost, of the heavy conductors.

Before leaving the subject of the transformer connections

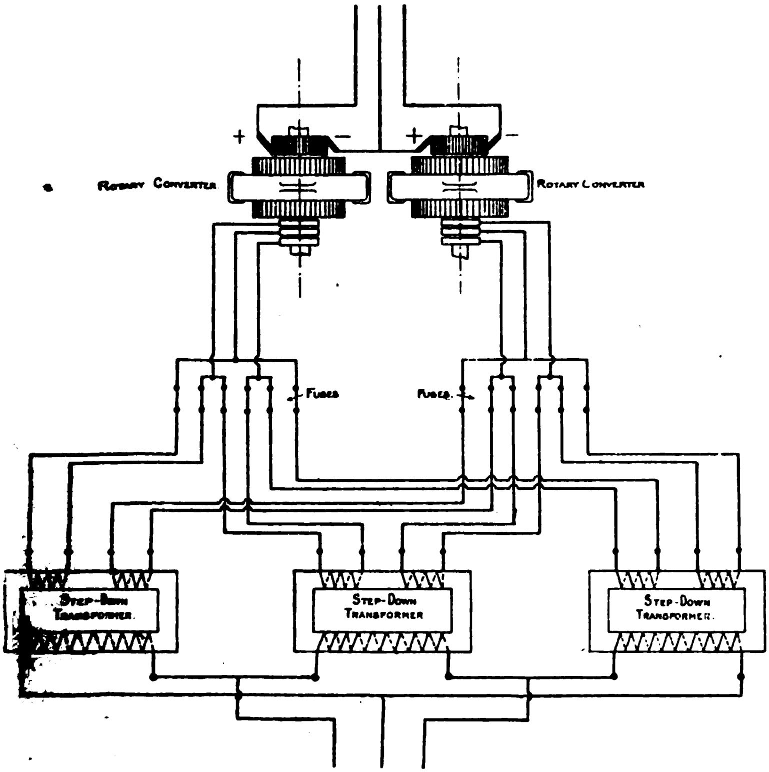

FIG. 2.—Connections for Rotary Converters in Parallel Feeding Three-wire System.

for three-phase rotary converters, it may be mentioned that a case sometimes arises in practice in which a special transformer arrangement is necessary. When two or more rotaries are not arranged to be fed (for any special reason) from separate groups of transformers on the alternating-current side, and they are connected to a three-wire network on the direct-current side, then it is necessary to wind each

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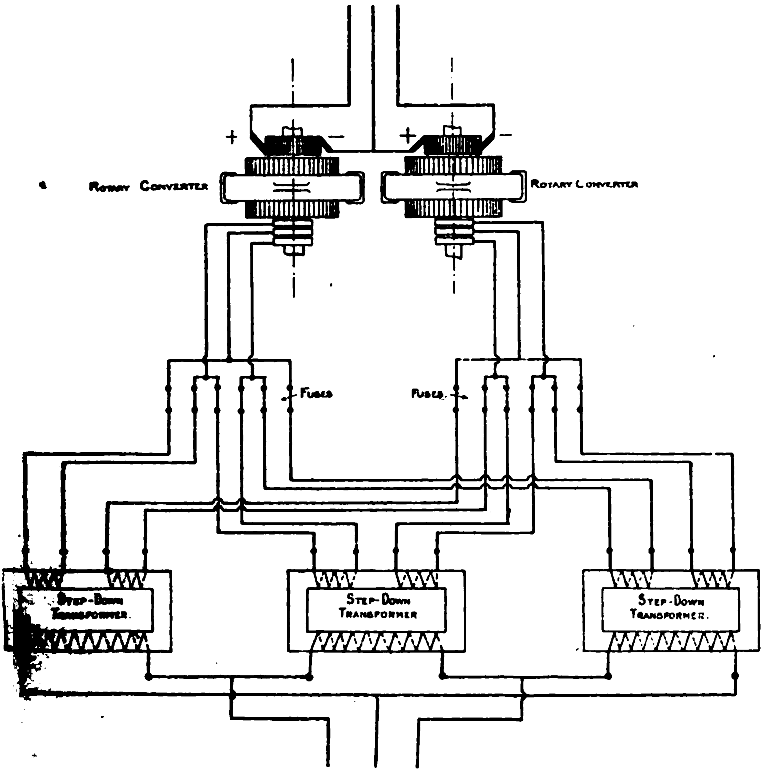

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unit forming the group of (two or three) transformers feeding the rotaries with a multiple secondary winding, as described above, the arrangement being as shown in Fig. 2, illustrating the connections for two machines. That is to say, it is impossible to operate a number of rotaries feeding a three-wire network from common bus-bars on the alternating-current side. The reason is readily apparent from the figure—the slip-ring sides of the machines cannot be *directly* paralleled, owing to the connection already existing on the direct-current side—if they were directly joined a disastrous short-circuit would naturally result. It may be noted in passing that the arrangement of the fuses in the secondary circuits of the transformers shown in this figure [1] (each conductor coming from a slip-ring is fused twice) is a good one, for if one transformer gives out, the service will not be interrupted, for the reason already given above.

There is, however, a certain advantage in using *star-connected* transformers for converters feeding three-wire systems, for by the adoption of this form of connection better balancing can be attained; the secondary neutral points of each group of transformers may be profitably connected to the middle wire, which latter may or may not be earthed. Under these circumstances each rotary would be fed from a separate group of transformers.

The next question arising in connection with the equipment of a rotary converter substation is that of pressure regulation. It is clear that with motor generator substations (whether asynchronous or synchronous), this question hardly comes in, for, as already indicated, the regulation is performed wholly on direct-current machines of standard design, either automatically or by hand, in the simplest possible manner. The conditions are, however, quite different with rotary converters, because the pressure on either side is practically totally independent of the field strength (although not of the field configuration), and consequently, the direct-current pressure cannot be varied by regulation on the fields alone.

There are two commercial ways of regulating rotary converters, each depending upon the same principle, namely, that of altering the pressure on the slip-rings in order to get

[1] This arrangement of fuses for such a case originated with the General Electric Company (U.S.A.).

a corresponding alteration on the direct-current side; as already pointed out, the ratio of the two pressures is practically a constant. The first method consists in varying by hand the impressed pressure on the slip-rings, and can be employed in two ways—either the impressed pressure can be altered by altering the ratio of transformation of the step-down transformers, or it can be altered by means of an "induction regulator." In the first case, the step-down transformers are so arranged in conjunction with a multiple contact switch that either the number of secondary turns, or the number of primary turns, can be altered by hand, thus altering the ratio of transformation; the transformers supplying each rotary have their regulating switches interlocked, so that the turns are cut in or out simultaneously. It is obvious that this method has several disadvantages, the most serious being those of first cost, and difficulty of operation. If the regulation is performed on the primaries, the switches become somewhat difficult and expensive to construct properly, on account of the high pressure of the circuits into which they are connected, while if the regulation is performed on the secondary sides, the expense becomes even greater, on account of the heavy currents to be handled, while the difficulties that arise with the contact surfaces of all regulating switches for heavy currents are well known. But in addition there is the difficulty of arranging such switches to regulate gradually, and to avoid short-circuiting the sections of the transformer winding connected to the contacts of the regulator, as these sections are being cut out or in. Consequently the employment of an induction regulator which does not suffer from any of the above-mentioned defects, and which has but small losses as a rule, will give the best results if hand regulation of the rotaries is asked for or desired.

On account of difficulties connected with insulation, induction regulators should be connected into the secondary circuits of the step-down transformers. As usually constructed, such regulators consist of an iron core arranged in connection with a shunt and series winding in each phase in such a manner, that a movement of the core will decrease or increase the mutual induction between the two windings. Thus if the core is moved inwards, the pressure on the converter slip-rings is reduced, on account of the inductive

action of the shunt winding on the series winding, while as the core is moved outwards, the effect of the shunt coils on the series coils becomes less and less, until at the end of the travel of the core, the pressure on the slip-rings is practically the full pressure of the transformer secondaries. Such an apparatus is easy and cheap to construct, and very effective in operation, a range of six per cent., up or down, being easily attained; moreover, it can be readily arranged to be operated from a distance, and having no contacts or moving conductors, is unlikely to get out of order.

A modification of the induction regulator, first devised, the author believes, by Mr. M. B. Field, is shown in Fig. 3; it possesses the advantage of being somewhat more efficient than the induction regulator described above. The secondary of each step-down transformer has an extension in the form of some extra turns capable of carrying about 25 per cent. of the full secondary current; these extra turns are connected to a small regulating switch, and to the windings of smaller section of a small auxiliary transformer (with ratio say 1 : 4) as shown. The secondary of the auxiliary transformer is in series with the low pressure circuit, and adds or subtracts a small E.M.F. to this circuit as desired. It will be seen that both the voltage and current can be very readily handled, without undue expense, and, moreover, the supply is not interrupted should the regulating switch get out of order.

The second method of varying the impressed pressure on the slip rings of the rotary, in order to get the desired direct current pressure, is of considerable technical interest. Briefly, it consists in compounding the rotaries, and providing a certain amount of self-induction between the terminals of the transformer secondaries and the slip-rings of the machines, if not already existing, by inserting choking coils in the various leads. The rotary converters, being synchronous machines, operate at a power-factor determined wholly by the field excitation; for an alteration of the latter with a given load on the machines, increases or decreases the power-factor of the alternating current circuits; for each load on the rotary, there is, of course, a certain excitation that will make the power-factor a maximum, in accordance with the well-known "V" curve. Let now the shunt winding on the fields of a rotary converter, arranged

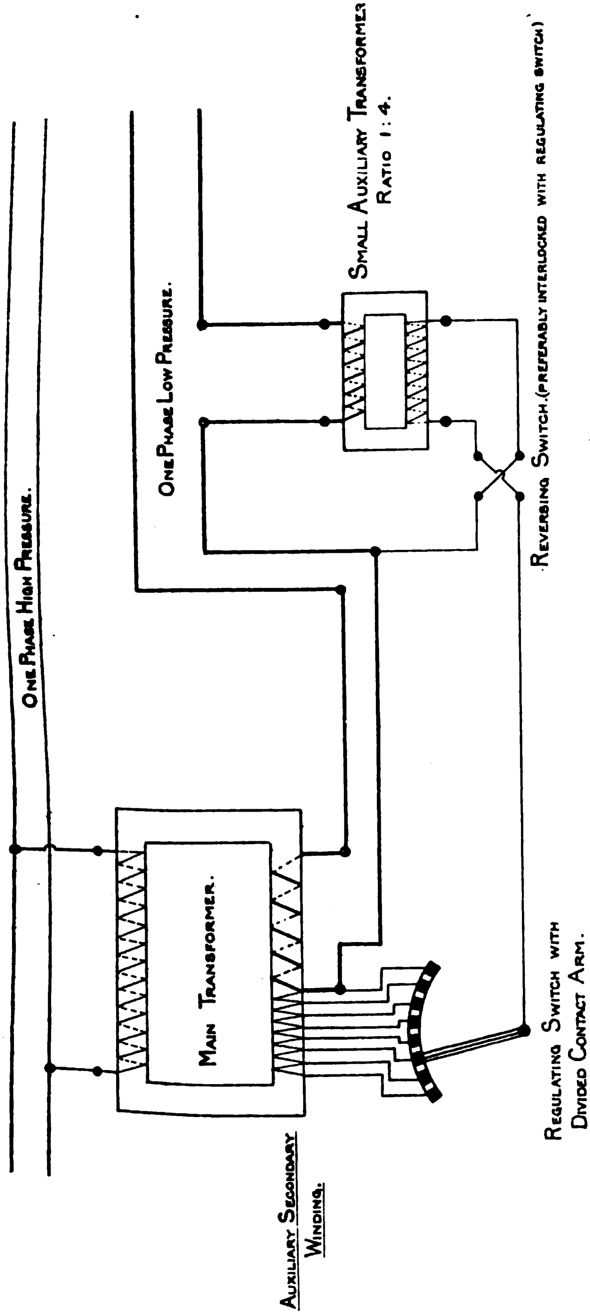

FIG. 3.—Diagram of Connections for One Form of Induction Regulator.

with compound winding, and, if necessary, with small choking coils, be so adjusted that when operating at no load, the machine takes a certain amount of lagging current, say 30–40 per cent. of the full-load current, partly due to the under-excitation, partly due to the reactance in each phase. As the load comes on, the field flux increases, on account of the current in the series winding—that is, the lagging current diminishes, and therefore the impressed pressure increases, producing a corresponding rise in the direct current pressure; this strengthens the fields still more (on account of the shunt winding), until a balance between the two pressures is attained. At full load, the field flux is at its working maximum; the input current will be by this time leading, due to the over-excitation having wiped out the lag produced by the reactance, and the direct current pressure will be raised to the correct value, on account of the increased pressure on the slip-rings. By suitable proportions of the reactance and field windings, excellent pressure regulation can be attained in this way, in a perfectly automatic manner; it is perfectly easy to arrange for the direct current pressure to be over-compounded 10–15 per cent., the actual regulation being nearly as good as with an ordinary over-compounded direct current machine,[1] provided the pressure at the ends of the feeders in the substations is maintained as nearly as possible constant. The only objection to this method of regulation is the influence it has upon the regulation at the feeding points—that is, at the high pressure bus-bars in the sub-stations, for with a number of the latter in parallel, the variation of the power-factor naturally means that the attainment of constant pressure at the ends of the feeders becomes a difficult matter.

The extent to which over-compounding of rotaries can be carried—by means of the above described method—depends mostly upon the rating of the machine with regard to the work it has to do. The limit is of course reached when the current running into the rotary is made to lead (by increasing the exciting current) the impressed pressure by

[1] With a rotary converter of standard design, the change of field flux necessary in order to get the desired amount of over-compounding is much greater than is required with the equivalent direct current machine, for the direct current pressure is not proportional to the field flux but proportional to the impressed pressure on the slip-rings.

90°, for then the inductive E.M.F. of the choking coil (which is 90° behind the current) is in phase with the impressed pressure, and consequently boosts it by that amount; if the current lags behind the impressed pressure by 90°, the inductive E.M.F. of the coil is half a cycle behind the impressed pressure, and diminishes the latter to a value given by subtracting the inductive E.M.F. of the choking coil from the impressed pressure. Neither of these limits are found in practice, for if the angle or lag or lead exceeds certain well-defined values (depending upon the shape of the "V" curve—that is, upon the armature reaction of the machine), the rotary will naturally not carry its rated load. The more liberally rated is the converter, the greater is the range of regulation attained; if the amount of over-compounding required is large (say 15–25 per cent.), the rotary must be chosen large for the work it has to do, although not in this proportion.

Compound wound rotary converters are connected and paralleled on the direct current sides in precisely the same manner as similar direct current machines, equalising bus-bars and switches being used, and therefore the same precautions have to be taken with them should accumulators be used in parallel with the low-pressure feeders.

From what has been said above, it will readily be seen that of the two good methods put forward for regulating the pressure on the direct current sides of the machines, that best adapted for the requirements of lighting work is given by the employment of induction regulators, allowing the pressure to be gradually varied by hand in accordance with the slowly varying load; for traction work, the employment of compound windings (that is, regulation by lagging and leading currents) is preferable on account of the large range of regulation required, and the rapid variations of the load. In some special cases, however, the combination of the two methods will give very good results.

With regard to the starting of rotary converters, all the remarks already made regarding the starting of synchronous motor generators are applicable, as the only difference in this respect between the two classes of machine is that rotary converters are invariably arranged to be self-exciting from their direct current sides. Wherever possible then, such machines should be arranged to be started from the

direct current side, either from the bus-bars, or from an auxiliary asynchronous motor generator. As in the other case, this latter indirect method of starting is far preferable to any other, if no direct current is available at the switchboard.

The next best method to this is that given by induction motors directly coupled to the shafts of the rotaries, while the fourth and last method available (briefly noticed already in connection with the starting of synchronous motors) simply consists in switching the machine directly on the high-pressure lines. As this method has been put forward in connection with several important British schemes, and is in use in more than one of them at the present time, it may not be out of place to devote a few words in its consideration, although in general the method is objectionable.

Any modern synchronous polyphase motor can be started up without difficulty from the high-pressure lines, no matter how constructed; that is, whether the field poles be solid or laminated, whether provided with damping coils or not, &c.—it is only a matter of sufficient starting-current and good mechanical design. This method of starting, as used in connection with rotary converter plants, is as follows: The direct current main and field-switches are opened, only a volt-meter being left across the direct current side, and then the line-current is switched on the slip-rings, either at full or reduced pressure, this latter being arranged for by an alteration in the number of secondary turns on the step-down transformers. Owing partly to the eddy currents in the pole pieces, metal cheeks of field-bobbins, damping coils (where these are used), but principally to the hysteresis lag in the pole pieces, the rotary immediately starts, and is very soon up to synchronous speed. The volt-meter (already referred to) on the direct current side indicates nothing at the moment of starting beyond very feeble oscillations of the pointer, for the current traversing its coils is of course alternating; but as the rotary increases its speed the pointer begins to move backwards and forwards over the scale, its movements corresponding to the rapidly diminishing frequency of the pressure at the direct current terminals; when synchronous speed has been reached the volt-meter pointer will again be

steady, for the current through it is now a direct current. The proper time for putting on the field-current is just before synchronism is reached, and is indicated by the volt-meter; when the beats of the pointer are slowest, that is, just below synchronous speed, when the pointer is moving slowly from side to side over the scale, the field-current can be put in. But it may be noted here that it makes all the difference at which side of the scale the pointer is when the field-circuit is closed; one side is right and the other wrong, depending upon individual circumstances. If the fields have been put on when the pointer is at the wrong side of the scale, then the polarity of the direct current side of the converter will be reversed; with most machines this means that the rotary must be switched out and synchronised again in order to get synchronism at the right pole. In order to make quite sure that the machine has synchronised at the right pole, it is good practice to provide a pole indicator on each direct current panel, so that after the excitation has been put on, the polarity of the direct current side can be checked before the rotary is connected to the direct current bus-bars. Needless to say, a lamp can be substituted for the volt-meter mentioned above across the direct current terminals—it will be bright at the first moments of starting, and also when the neighbourhood of synchronous speed is reached, while between these limits the light will pulsate, and the excitation should be put on when the light is pulsating slowly, the lamp being either bright or dark, according to circumstances.

It will be readily understood that the above remarks regarding the right time to put on the excitation in order to get the right polarity are only applicable to the case of self-exciting machines; if the machines are bus excited, which is very seldom, the converter will pull itself round under protest to the correct polarity with a great rush of current, no matter at which pole the machine has synchronised. A point worthy of note is that even without the exciting current the rotary will come up to absolute synchronous speed, for there is no induction motor action with the rotary converter or synchronous motor. A rotary converter can operate without field excitation, by reason of the heavy lagging currents that would run through its

armature windings under these circumstances; these wattless currents magnetise the fields to the extent necessary to produce the balancing back E.M.F. of the armature. However, such a method of operation cannot be commercial, for the machines would not carry their rated load; the heavy lagging currents would overload the mains and destroy the pressure regulation of both sides of the system, and the rotaries would spark and hunt. Up to the present, the author has not made any tests on the operation of large rotaries without field excitation, for there is generally little time for such experiments when putting down plant, and, moreover, they may turn out to be somewhat costly; it is an interesting question, however, and it would be of value to know from those who have actually made tests on large units under commercial conditions whether the objections given above are as real as they appear to be. Perhaps with machines having high armature reaction (small air-gaps, &c.) the full load could be carried without the machine stopping, but its performance under these circumstances could hardly be otherwise than poor, quite apart from the bad effect produced on the system; moreover, rotaries with considerable armature reaction have a greater tendency to hunt than those with very stiff fields.

When starting a converter in the manner above described, it is necessary to take certain precautions until synchronism is attained; the series field-windings must be open as well as the shunt, and these latter windings must be opened in five or six places. Otherwise they would break down, due to the large E.M.F. (many thousand volts) induced in them by the alternating flux of the armature. Also, as the starting current will never be less than twice the full-load current, even if damping-coils are used, and will frequently be of the order of three or four times the full-load current, it is necessary to make arrangements for short-circuiting the amperemeters and fuses, otherwise they would be damaged by the overload.

The great objections to the above described method of starting are of course the large starting-current required, and the risk of getting the wrong polarity; the former will wholly upset the pressure regulation of the system, partly on account of its magnitude, but principally because of its low power-factor, while the latter might cause an

accident, and in any case would cause time to be lost when adding a machine to the circuit. For lighting work the employment of this method is absolutely out of the question.

II.—Some Features of Working.

With regard to asynchronous motor generator sub-stations there is practically nothing to be said, on account of the simple character of the equipment and its operation. Two points must be kept in mind however—the sets must be run as fully loaded as possible, and the motor air-gaps must be watched. As the power-factor of the motors will be less than 90 per cent. below three-quarter load, running the machines well loaded becomes even of greater importance than with other classes of electrical machinery, in order to avoid heavy, lagging currents in the feeders. As a matter of fact, it is a good thing to overload such motor-generators (in moderation) before adding a machine to the bus-bars, for then a high power-factor over a wide range of load is assured; the risk is very small, on account of the rapidity with which another set can be started up and put on the circuit. The other point just mentioned—relative to the air-gaps—is of some importance on account of the small clearance in the motors. As with all induction motors, the air-gap length is determined wholly by mechanical considerations, being made as small as possible in order to get high power-factors, it becomes necessary to check it from time to time, in order to make sure that the gap at the bottom has not decreased to a dangerous extent. With large induction motors the gap (iron to iron) will be originally about $\frac{1}{450}$ of the rotor diameter—a 200 B.H.P. motor would thus have a clearance of 0·1 inch with a rotor diameter of $3\frac{3}{4}$ feet, so it will be seen that no considerable diminution of this length can be allowed on account of the magnetic pull, even assuming exceptionally stiff shafts. The stator case of such motors should never be cast with the bed-plate, for if it is separate a thickness or two of metal foil can be inserted between the feet of the case and the bed-plate seatings, by removing which the gap at the bottom can be increased when the brasses have worn

to such an extent that something must be done, and yet not enough to justify their replacement altogether.

With substations employing synchronous machinery, such as synchronous motor generators or rotary converters, several highly interesting and important features of working present themselves. The first is the regulation of the power-factor, and has already been mentioned in connection with rotary converters—the power-factor at any load on the machine can be regulated to the extent necessary in practice by adjusting the field excitation. The curves shown in Fig. 4 gives a good idea of the practical case—they are curves taken for the purpose of this paper from the 650-H.P. Kolben three-phase motor forming part of the motor generator illustrated in Plates I. and II., and whose test curves are given in Fig. 6. The shape of the no-load "V" curve of a synchronous machine is an indication of its performance—a very broad curve indicates, for instance, a motor of but moderate overload capacity, and one that will require but small alterations in the excitation for varying loads; while a very steep curve indicates a machine that must work always with its excitation properly adjusted, otherwise its overload capacity will be small and its parallel running properties inferior; at the same time this latter type of curve is a characteristic of machines with close pressure regulation.

When the machine is loaded the "V" curve alters somewhat with regard to position and shape on account of the increased armature leakage, as indicated in Fig. 5. The amount of this alteration is an indication of the quality of the armature design in this respect—the smaller the alteration in shape, and the less the inclination of the axis *a b* from the vertical, the smaller the pressure drop, and the smaller the increase of excitation necessary for the motor from no load to full load in order that it may work under the best conditions.

Synchronous machines, whether motors or generators, should be so designed that the shape of their "V" curves lies between the two limits mentioned above, for then excellent parallel running, high overload capacity, and good pressure and excitation regulation will all be attained; otherwise one or other of these necessary good qualities will be attained at the expense of the remainder. Running

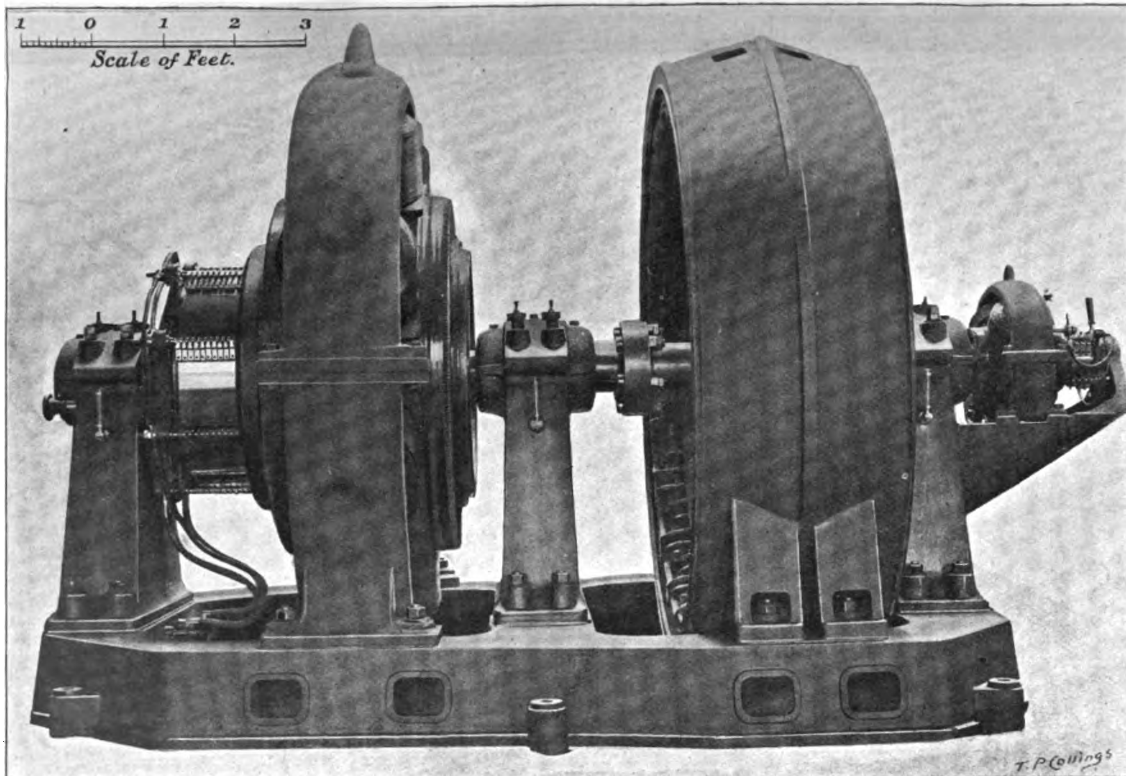

PLATE I.—450-Kilowatt Three-Phase Motor Generator, 240 Revolutions per Minute; 48 Cycles; 3,000–600 Volts.

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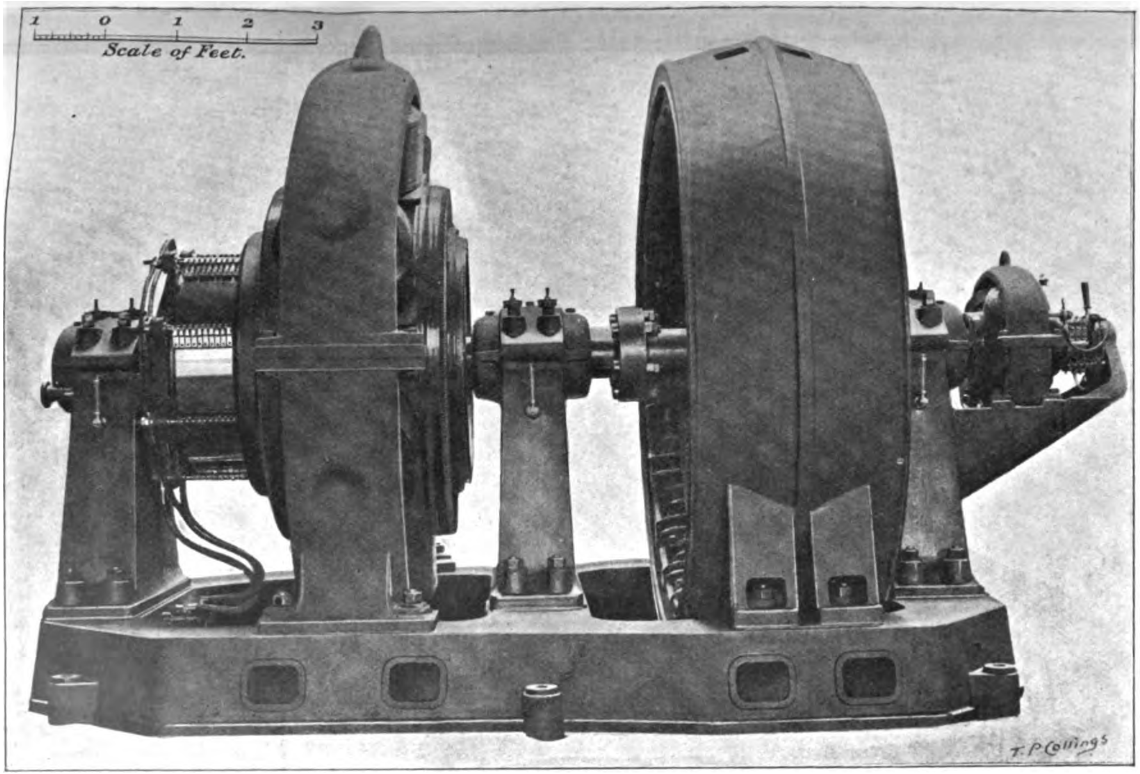

PLATE I.—450-Kilowatt Three-Phase Motor Generator, 240 Revolutions per Minute; 48 Cycles; 3,000–600 Volts.

as generator, then, the full-load drop of the machine at constant speed and excitation should be in the neighbourhood of 5–6 per cent. with 100 per cent. power-factor, and 18–20 per cent. with 80 per cent. power-factor. Better regulation than this is not asked for in modern practice with units of medium and large output; nor is it desirable, especially when substations employing synchronous machinery are fed from them; with better regulation abnormal synchronising currents may pass between the main units, inviting hunting on the part of the rotary

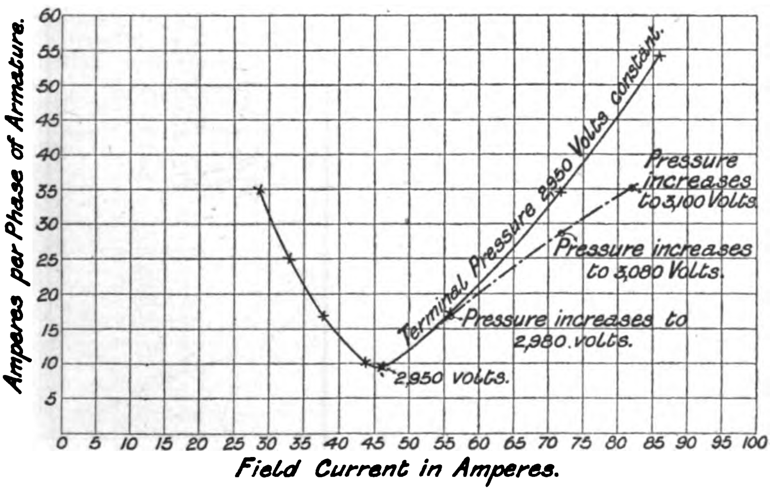

FIG. 4.—"V" Curves for 650 B.H.P. Three-Phase Synchronous Motor. Constant Speed. Constant Load.

converters or synchronous motors. Of course the generators would become at the same time much too heavy and expensive.

Returning to the actual no load "V" curve shown in Fig. 4, it will be seen that when running practically without load, at the constant impressed pressure of 2,950 volts per phase, attained by regulating the bus-bar pressure in the power station, the excitation for the minimum armature current of 9·5 amperes is 46 amperes; a reference to the no-load characteristic of the machine (Fig. 5) shows that with this minimum value of armature current an induced pressure of 2,250 volts per phase is attained. With minimum armature current at a given load, the difference

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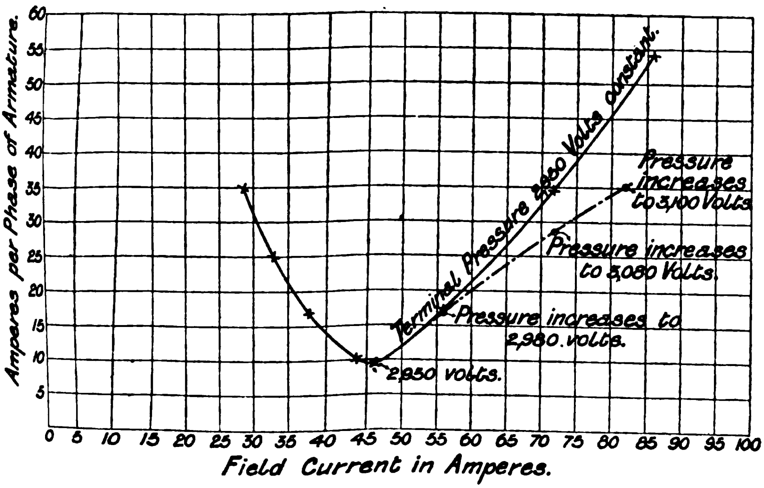

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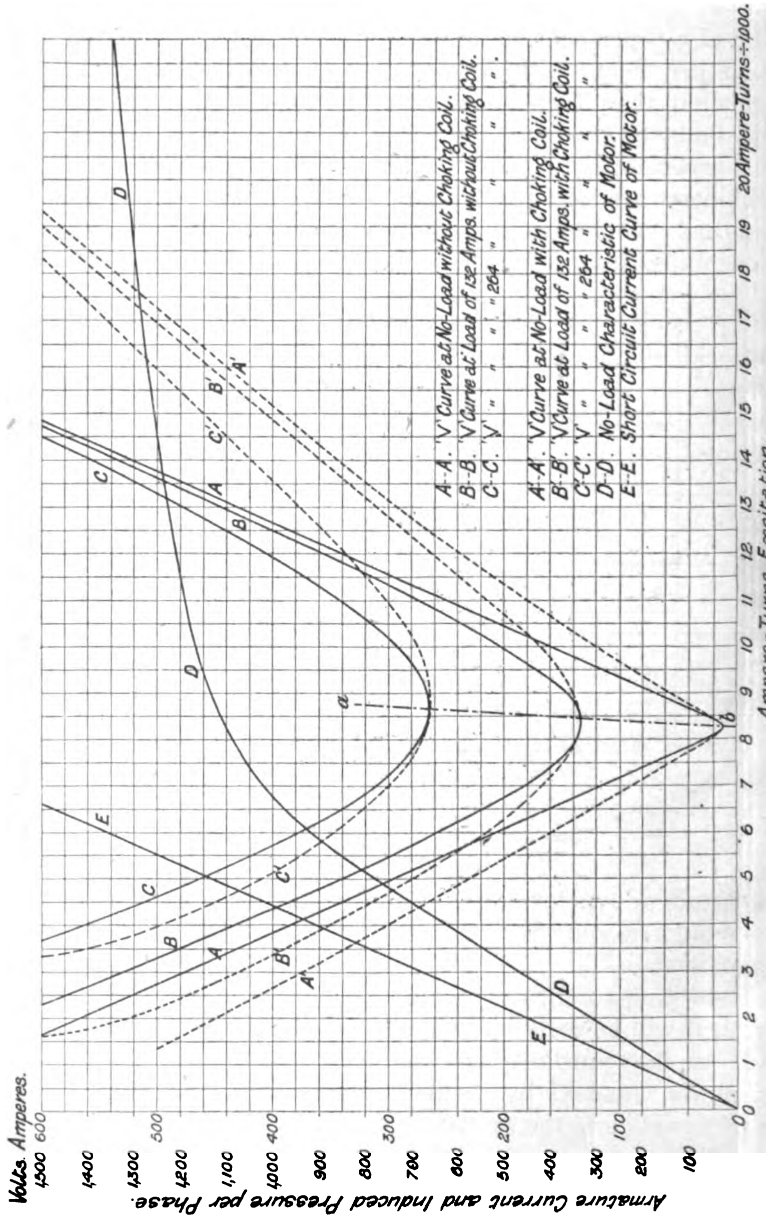


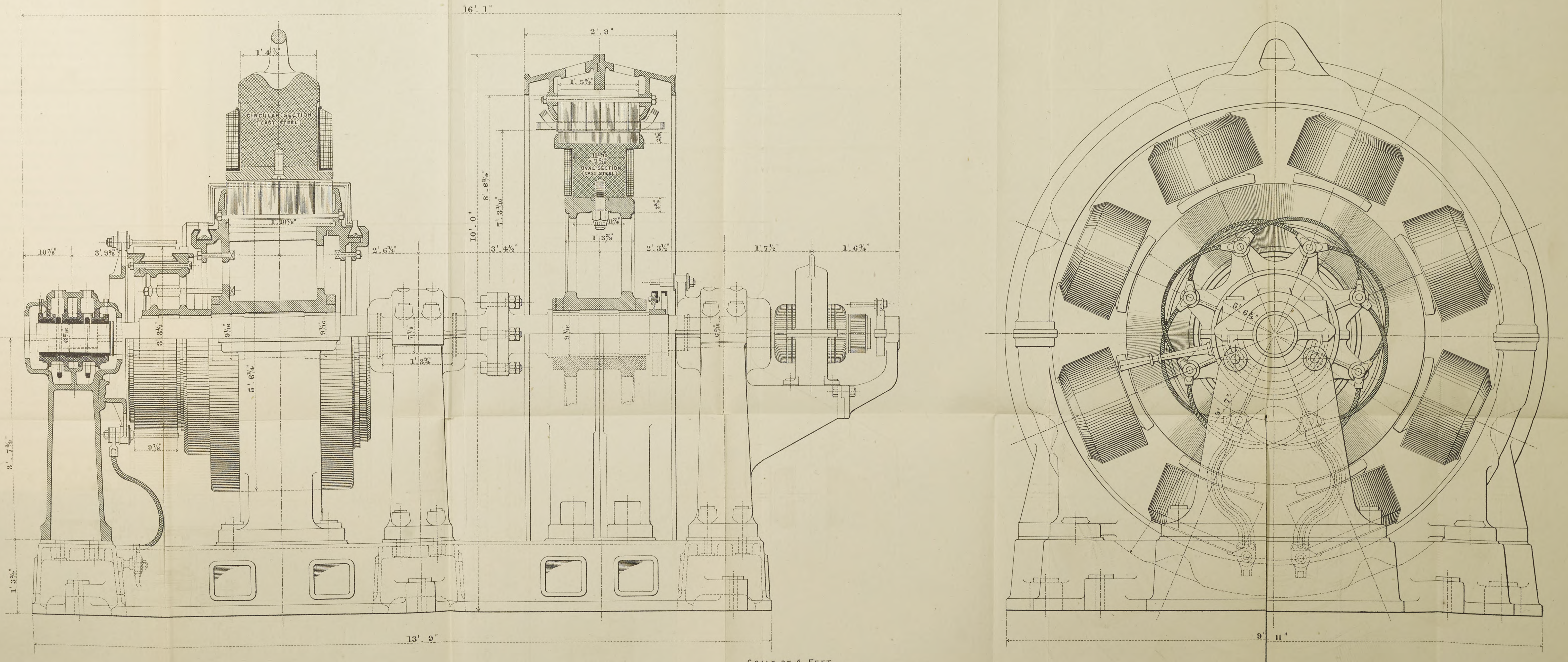
FIG. 5.—"V" Curves for 725 B.H.P. Two-Phase Synchronous Motor at Constant Pressure. Constant Speed. Three Different Loads.

450 Kilowatt Three Phase Synchronous Motor Generator.

PRAGUE TRAMWAYS.

SPEED 240 R.P.M.; FREQUENCY 48 CYCLES; VOLTS 3000/600-650.

Constructed by Kolben & C[o] L[td] Prague, Austria.



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between the impressed pressure and the back pressure, that is, the difference between 2,950 and 2,250 volts in this case, is a measure among other things of the quality of the motor from the point of view of pressure regulation; the difference between the two pressures under these circumstances is due to the impedance of the armature and to the pressure and current beats which occur with all synchronous machinery—with a constant load and excitation on a synchronous motor or rotary converter, the back E.M.F. is continually changing its phase relative to the impressed pressure, a result directly due to variations in the angular velocity of the generators, assisted by the momentum of the machine itself. At constant impressed pressure a decrease or increase of excitation, corresponding to a decrease or increase in the back E.M.F., causes a fairly rapid increase of the armature current (and apparent watts) taken by the motor. At a given load, for any value of the motor excitation, a definite value of back E.M.F. takes such a (mean) position in the vector diagram that the resultant of it and the impressed pressure has a value equal to the impedance pressure of the armature. If the excitation be increased above the value corresponding to maximum power-factor, the impressed pressure at the terminals of the motors must of necessity lag behind the current in order that the above-mentioned relations are maintained; for the impedance pressure has a constant phase angle relative to the current in a given machine. On the other hand, if the excitation is less than the critical value, then the impressed pressure must lead the current for the same reason.

From the "V" curve, and knowing the various losses and constants of the machines, it is possible to make an approximate calculation of the amount of lead or lag that can be given to the current. For this 650-H.P. motor running light, the maximum lead works out to be about 75 degrees, while the maximum lag is about 70 degrees. In general, it is not possible to obtain more of the "V" curve than shown in Fig. 4, for, if pushed much farther, the running of the motor becomes unstable, hunting is set up, and the machine drops out of step.

The two legs of an experimentally obtained no-load "V" curve always differ—one is invariably straight, the other

convex (cp. Fig. 4). In this respect, the curves thus obtained from well-designed commercial machines differ somewhat from the theoretical curves, in which, as Steinmetz has proved,[1] one leg is convex, the other concave. This difference between theory and practice in this respect is due to armature reaction and to the influence

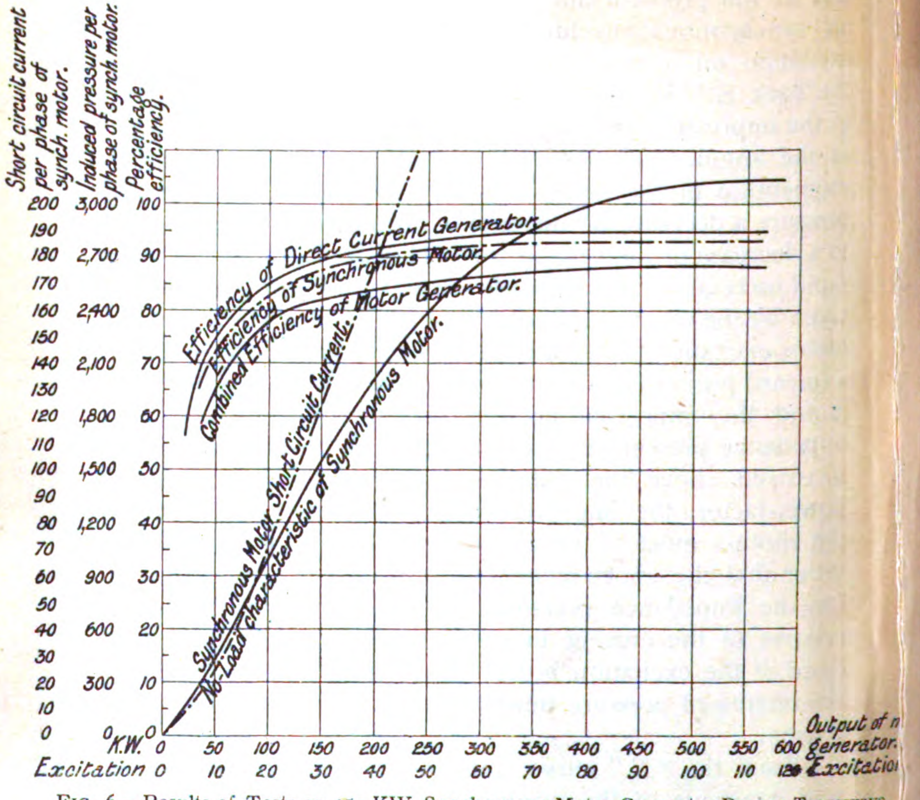

FIG. 6.—Results of Tests on 450 KW. Synchronous Motor-Generator Prague Tramways. Speed 240 Revs. per min. Frequency, 48 Cycles. Volts, 3,000/600–650 per Phase.

of the highly saturated armature teeth when the current is greatly leading or lagging.

The dotted curve to the right of the "V" curve (Fig. 4) illustrates clearly what happens in a transmission plant when the impressed pressure on the synchronous machinery is not maintained constant, but is left to take care of itself;

[1] See *Alternating Current Phenomena*, by C. P. Steinmetz (Whitaker & Co., London and W. J. Johnston, New York).

the pressure at the ends of the feeders rises steadily with increased excitation of the synchronous machines. In this case the 1,000 kilowatt generator supplying current to the motor (through a long three-core cable) had its excitation adjusted once for all at the beginning of the second test, to such a value that the impressed E.M.F. on the motor was the same as before, namely 2,950 volts, *when the armature current had its minimum value.* The excitation of the synchronous motor was then increased, the dotted curve showing the increase of (leading) armature current; the effect of this was to raise the impressed pressure on the motor, that is, the pressure at the ends of the long feeder, from 2,950 volts to 3,100 volts. That is to say, the drop in the feeder (which possessed a considerable inductive drop, owing to the presence of a choking coil in series at the station end) was first wiped out, and then the pressure at the substation end was gradually increased to the extent of over 5 per cent., simply by increasing the excitation of the motor. The frequency of course was constant throughout the tests, and consequently the motor speed also.

A little consideration of the above described characteristic of synchronous motors will show at once how valuable machines of this class become in connection with any transmission plant, on account of their condenser action; it will also show the great superiority of synchronous motor generators and rotory converters over an asynchronous machine for substation purposes, from the point of view of the regulation of the system, and the line losses, &c. Instead of having a lagging idle current throughout the system, wasting energy and impairing the regulation at all points, the power factor of the system can be kept practically at or above unity throughout, the effect of pressure drop in the feeders can be nearly annulled, if desired, and there will be no other losses except those corresponding to the load, unless it is desired to work with a considerable leading current in order to raise the pressure at the substation ends of the feeders, as described.

It is not possible to get a power-factor of *exactly* unity in the circuit, by adjusting the excitation of a motor running light, so as to obtain minimum armature current. That is to say, the bottom of the "V" curve does not mean that the current running into the armature of the motor is in phase

with the impressed pressure; it is very nearly in phase, but not quite, owing mostly to the difference in the E.M.F. waves of line pressure and motor pressure. Large synchronous motors, when well loaded, and if of good design, generally have full load power-factors of 96 to 98 per cent. when working at the excitation corresponding to minimum armature current.

In practice the utilisation of the phase rectifying properties of synchronous (motor) machinery works out as follows. With rotary converter substations, if the machines are compounded, the power-factor of the system will be nearly unity at about half load, the current lagging somewhat before this, and leading afterwards, in accordance with what has already been said in this connection on page 718; at full load the drop in the feeders supplying the substation will be considerably reduced. If the rotaries are shunt wound, or if synchronous motors are employed, the field current is so adjusted that the power-factor is highest at about three-quarter load—at both lighter and heavier loads, the current is somewhat out of phase, the minimum power-factor being say 0·95. Or, if heavy overloads are expected, the machines had best be somewhat over excited at full load in order to increase the impressed pressure, especially if synchronous motors, for the overload capacity is thereby increased, the torque being proportional to the square of the impressed pressure. Thus with a synchronous motor generator substation, if the motors are well designed, it is not necessary to alter the excitation continually with the load; but two adjustments between no load and full load will be generally advisable, in accordance with what has been said above. The small amount of field regulation required in practice with well-designed synchronous motors is well illustrated by Fig. 5.

If a substation equipped with synchronous machinery has to work in parallel with large inductive loads, such as large induction motors, or another station arranged with asynchronous motor generators, it is as well to arrange for the lagging current to be balanced by the synchronous machines. That is to say, the synchronous motors or rotary converters will be liberally designed, in order that they may carry the balancing leading currents (and increased excitation) in addition to the load.

A word or two may be said here regarding the overload capacity of the three classes of substation equipment. With motor generator substations, what may be termed the permanent overload capacity depends only on the direct-current machines, that is to say, it will be in general about 20 per cent. for two hours, the position of the brushes on the direct-current machines remaining unaltered. With rotary converters the corresponding overload capacity is of course greater, and in practice is determined as a rule by the commutator heating. The commutators of rotary converters invariably have peripheral speeds bordering upon the upper limit of good practice—say 3,000 feet per minute —consequently an overload of about 30–40 per cent. for two hours is about as much as can be furnished without overheating the commutators. If it were not for this, and provided the field system was well over-excited, the overload capacity could be safely taken to be 50–60 per cent. for the time stated; it would be determined by the permissible safe temperature rise of the armature coils and step-down transformers. It is hereby assumed that these latter are artificially cooled by means of cooling pipes in the oil, or by forced draught, the normal temperature rise being 35° C., conforming in these respects to good modern practice.

What has been called the "permanent overload capacity" above is however really of minor importance in practice, for the plant would not be subjected to such treatment except when being taken over, or when a breakdown occurs. The important point, particularly with substations feeding tramway or railway systems, is the momentary overload capacity, that is t · say, the effect of short circuits of brief duration has to be considered.

Regarding this point, it may be at once stated that the three classes of equipment are perfectly satisfactory, and moreover, from this point of view, there is but little to choose between them. Well-designed asynchronous and synchronous motors and rotary converters fed from a well-designed power-station will all stand overloads of 100 per cent. for a few seconds without falling out of step, the two classes of synchronous machines behaving in a very similar manner to the asynchronous machines. This is about the safe limit of overload capacity for standard machinery—the short circuit, or whatever it may be, causing the momentary

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overload is naturally unexpected, and consequently the plant as a rule cannot be stiffened up by field regulation, to stand more, or to stand this amount for a longer period, with safety. It does not follow that the machines will drop out of step, although asynchronous motor generators designed for high efficiency would probably pull up; the synchronous motors or rotaries would generally become unstable in their running, and start hunting.

With regard to the falling out of step of synchronous machinery, it may be observed here that once this happens the inherent tendency of a machine to pull itself in again is determined by the torque it can exert in a very short time, namely, half a cycle; consequently, if there is any load on the machine, it must necessarily pull up.

Should a momentary short circuit pull out the circuit breakers in the power-station, or otherwise break the circuit on the alternating current side of the converting machinery, it is always necessary to give the substations time to shut themselves down, rather than immediately replace the circuit breakers, while the converting machines are still turning. Under these latter circumstances even induction motors will not run up to speed, while the synchronous machinery forms simply a pulsating short circuit across the mains, a synchronous motor or rotary acting alternately as motor and generator relative to the transmission lines, and gradually pulling up. Before this happens, the circuit breakers will be out again; apart from this it would in general be impossible to keep in the circuit breakers on the direct current sides of the converters.

One of the most important questions to be considered in connection with the design and operation of a synchronous substation equipment is that of parallel running. The converting machines have not only to run perfectly in parallel with one another, but the various substations have to run perfectly in parallel with one another, and with the power-station also. In most modern installations this requirement has been easily attained, but in others great difficulties have arisen, and have had to be got over at great cost before satisfactory working over the whole system was attained. It is, therefore, of interest to discuss as briefly as possible the leading features of the question.

With a rotary converter substation, for instance, unless

every detail of the system is thoroughly well designed, from the engines in the power-station to the rotaries themselves, there will be trouble with regard to the parallel running of the machines—that is to say, they will hunt. The term hunting, as applied to synchronous machinery of this character, means that while running at synchronous speed (as measured by a tachometer), the machines oscillate between themselves—that is, during a revolution they increase and decrease their angular velocity above the mean velocity, corresponding to exact synchronism, causing the armatures to swing backwards and forwards from a fixed point, (in a precisely similar manner to the swing of a pendulum), while still keeping in step. The effect of this is to cause the pressure on each side of the rotary to fluctuate more or less badly, so that working at constant pressure on the direct current sides becomes impossible. Once a rotary has started hunting, unless the small oscillations are immediately checked, they will invariably continue to increase in amplitude until the armature swings over and loses synchronism.

The running performance of synchronous (motor) machinery depends so much upon the variations in the velocity of the power-house engines during a revolution, and upon the oscillations set up by the engine governors, &c., that if these variations or oscillations exceed certain well-defined limits it becomes impossible to operate the substations successfully. That this must be so becomes clear when it is considered that every variation in the supply frequency, (during an engine revolution), has to be taken up by the substation machines against their own momentum, with the result that if the armatures get accelerated or retarded to any extent from this cause, hunting is bound to occur, and operation of the plant becomes impossible until the engines are working properly. This is a case in which the hunting of the converters is due to a well-defined cause outside the machines themselves.

But although hunting may be sometimes caused in this way, the speed variations in the engines are by no means a necessary accompaniment to it, for it may be started in a variety of ways (of which engine pulsation is one), and then increased by the action of the machines themselves. This latter case—that of hunting on the part of the rotaries

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when the power-house engines are entirely suitable—is of considerable interest.

A working explanation of what happens in this case is as follows :—Let a slight oscillation be set up between the machines, by any little thing that may occur with the most perfectly designed plant it is possible to have, such as a sudden large change in the load, a short circuit, or faulty setting of the brushes on one machine, or an engine hunting in the power station (due to a small mishap, &c.)—this slight oscillation is accompanied by a weakening and distortion of the field flux of the converter. The mere fact of there being an oscillation implies field distortion, for a fixed point on the armature during the swing is either a little ahead of, or a little behind, the true position (corresponding to exact synchronism) it should have at this instant. This means that the machine is acting either as a generator or motor, taking either a leading or a lagging current from the lines, and shifting the diminished field flux to one or other of the pole horns. The armature will now try to follow this change of field configuration, taking a large current in the reverse direction in order to do so. But this change of current immediately distorts the field flux in the opposite direction to a much larger extent, and the armature again tries to swing to the new position. Thus each oscillation of the armature gets larger and larger, and the field distortion is greater and greater, until finally the flux from the poles gets swept nearly entirely away from the pole faces to the pole horns and gaps between them, the machine eventually swinging out of synchronism. During these oscillations the converter is acting alternately as generator or motor, giving up to, or receiving power from, the other converters in parallel with it, giving them in this way alternately a push and a pull at the wrong times, causing them to start hunting also. The combined effect of the various machines in parallel is to increase the hunting originally set up, and if other substations are in parallel, the oscillations may also be taken up by the machines in these, the combined effect perhaps even reacting on the generators in the power-station, causing them to start oscillating also. It is thus obviously necessary to provide means of checking the oscillations while they are still small, otherwise they will get out of control and spread over the whole system.

The sparking and flashing over which frequently takes place at the commutators of rotary converters when hunting is directly due to the pulsation of energy, and to the field distortion and fluctuation, for good commutation under these conditions naturally becomes impossible. The distortion of the field is really the root of the whole matter, and if this is prevented, or reduced to a minimum, hunting cannot occur.

That the whole magnetic system of a rotary converter that is hunting is in a very disturbed state is made readily apparent during working. For instance, a spanner held in the hand between two field poles is strongly attracted with variable force. As a matter of fact, even when the machines are working properly there is a certain amount of field pulsation, it being sometimes easily possible to estimate the speed of the power-house engines from the small, quick movement of the pointer of the field amperemeter.

There are certain conditions of working which tend to cause hunting, or which make hunting worse should it be set up. An example of the former is difference in the form of the E.M.F. waves of generators and rotaries, which is in itself sufficient in some cases to start hunting, but such differences are, as a rule, not sufficient to give rise to serious trouble. On the other hand, machines with strong armature reaction, or working much under excited, are more liable to hunt than those with strong fields, because the magnetic flux is more readily distorted. For this latter reason it follows that over-excitation of the rotaries is a condition favourable to good operation. Again, the momentum of the converters should be kept as low as possible, for this apparently indirectly assists hunting, and in any case impairs the action of any device that may be used for damping the oscillations in their early stages. Some engineers state that hunting on the part of the substation plant is increased by the impedance of the lines, but the author has not as yet found this, and considers that a moderate amount of self-induction in the lines is directly beneficial. Capacity in the feeders, on the other hand, does appear to have some influence. In practice, however, it is generally difficult to separate the causes that assist hunting from one another. The main cause will generally be found to lie with the engines, and when this is removed, or when

the effects of field distortion set up by it are neutralised, the troubles generally disappear.

Synchronous motor generators are far less likely to hunt (with a given generating plant and transmission system) than rotary converters. This is because there is considerable armature reaction in the synchronous motors, which tends to damp the pulsations in the armature current should hunting be set up, and also because the field system is fed at a steady pressure, which is totally independent of the pressure at the ends of the feeders. But with unsuitable engines synchronous motors will hunt badly, the pressure on the direct current side being practically unaffected thereby, which is a point to be noted. The characteristic pulsations in the feeder pressure will, of course, occur to just the same extent as with rotary converters.

From what has been said above, it will be seen that to ensure the perfectly satisfactory operation of synchronous substation machinery, two points must be attended to. The first is to take great care with the selection and operation of the generating and substation plant, particularly the former, so that the tendency to set up hunting will be as small as possible; and the second is to provide means for getting rid of the hunting—that is, damp the armature oscillations in their earlier stages—should it be set up.

Some considerations relating to the design of the generating plant will be given later, while regarding the means for damping the oscillations a few remarks may be made here. As these oscillations are actual speed variations, it is evident that it might be possible to reduce them considerably by mechanical means, but the cost of devices for this purpose would be out of the question, to say nothing of other objectionable features. On the other hand, the oscillations are accompanied by, and intimately connected with, the field distortion as described above, and consequently if this distortion could be done away with, hunting would be prevented. Happily, very simple and effective means are available for suppressing the distortion of the field flux. All that has to be done is to fit the synchronous motors or rotary converters with "damping coils." This device, which is one of the many excellent ideas in polyphase working which have reached this country from the Continent *viâ* the States, is of the greatest value in such cases, and rarely fails to stop

the worst cases of hunting. All that has to be done is to bridge the poles of the synchronous motors or rotaries from

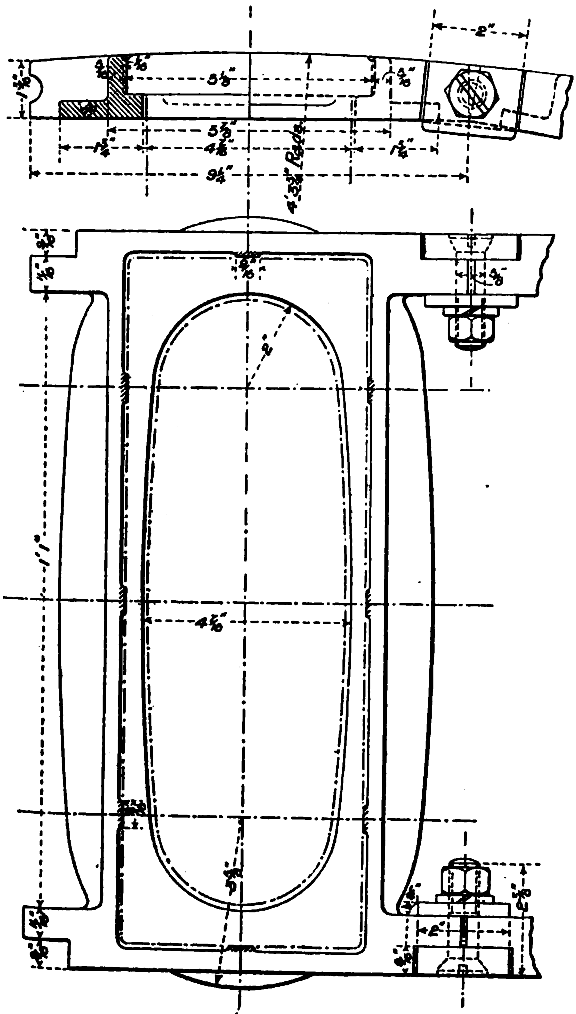

FIG. 7.—Combined Damping Coil and Field Coil Support for 725 B.H.P. E. and H. Synchronous Motor. Speed, 212 Revs. per Min.; Frequency 60 Cycles; Peripheral Speed, 5,500 ft. per Min.

horn to horn by copper plates or strips. These will have the effect of wiping out the distortion of the main magnetic flux, and therefore damping the armature oscillations, by

reason of the eddy currents produced in them by the flux due to the large leading and lagging armature currents—that is to say, as soon as the armature of the rotary or synchronous motor starts swinging, accompanied by the field distortion described above, the opposing flux produced by the eddy currents in the copper strips blows it away from between the pole-horns, and the oscillations are thus damped out magnetically directly they commence to form. It will be observed that the damping coils produce their effect just where it is wanted, namely, between the pole-horns. It is relatively of little use to put damping coils *round* the pole pieces; the metal is wanted at the horns of each pole, and between the horns of adjacent poles.

The dimensions of the copper strips connecting the poles of the motor or rotary can be varied within wide limits without making much difference to the damping action. The losses in them with actual rotary converters are found to vary from 0·5 to 1·5 per cent. of the output of the machine, depending upon circumstances. An idea of the actual dimensions of damping coils used in practice is given by Fig. 7, which illustrates the gun-metal damping coils, combined with the outside cheeks of the field bobbins, for the synchronous motor of the 500-kilowatt two-phase motor generator shown in Plates 3 and 4. The damping strips bridging the pole-horns of the rotating magnet wheel are cut away centrally, partly because the centre portion is not very effective, but principally in order to prevent the ventilation of the magnet wheel and armature being impaired.

As rotary converters will hunt upon slight provocation, such machines should always be fitted with damping coils, whatever the nature of the engines. They need only be used with synchronous motor generators when the power station engines are badly designed, unless lighting is done from the same feeders. In this case it will generally pay to use them. With water-power plants they are generally unnecessary for either class of plant. On the other hand, if the engines are very bad they should be used on the generator field poles as well, where they will have a precisely similar effect (for the case is similar), and will reduce the synchronising current between the generators practically to zero.

One result of hunting in the substations is that the current in the high-pressure feeders pulsates. As a matter

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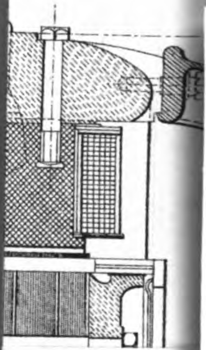

(180 degrees) from one another, and consequently satisfy the six-phase condition.

While the six-phase connection for rotary converters is more complicated and somewhat more expensive than the three-phase, yet it will undoubtedly pay to use it; as a matter of fact, it is somewhat surprising that the merits of this form of connection do not appear to be generally recognised, for Steinmetz and Kapp long ago pointed out that the output of any given rotary can be increased 40–50 per cent. by its use—that is to say, for the same mean heating of the armature coils, a six-phase rotary has an output 40–50 per cent. greater than the three-phase rotary, according to the value of the power-factor of the alternating-current side. As the output of any well-designed rotary converter is determined solely by the permissible temperature rise (there being no distortion of the field flux under usual working conditions—power-factor approximately unity), this increased output is a great practical advantage. Another advantage of the six-phase connection with rotary converters is that the heating of the armature is much more uniform—as is well known, in two- and three-phase rotaries, those portions of the armature winding on each side of the tappings to the slip-rings heat up considerably more than the remaining portions of the winding. With a six-phase winding, the maximum temperature rise on the winding will rarely exceed the minimum by more than 20 per cent.

It is not probable that the twelve-phase connection will take a place in practice, for the gain in still further increase of output and uniformity of heating would be more than counterbalanced by the increased cost and complication.

On account of the fact that all rotary converters have to be fed from step-down transformers, the switch-gear becomes more extensive, for although as a rule not necessary, it is good practice to provide switches in the secondary circuits of the transformers. There is, however, one case where such switches are absolutely necessary, and that is for two-phase rotaries arranged for starting from the direct-current side; in this case, unless the transformer secondaries are open, they become short-circuited (at the moment of starting) upon the armature winding, causing a great increase in starting current, and violent sparking at the commutator, until the machine is well towards full

speed. The heavy current switches in the secondary circuits are best mounted upon, or close to the transformers, which latter should be close up to the rotaries, in order to reduce to a minimum the pressure drop, losses, and cost, of the heavy conductors.

Before leaving the subject of the transformer connections

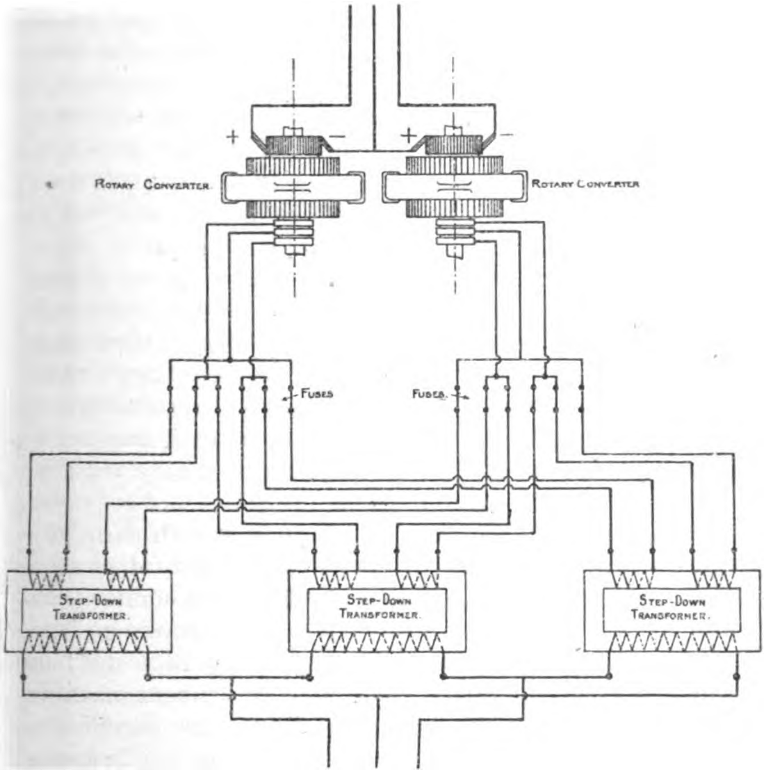

FIG. 2.—Connections for Rotary Converters in Parallel Feeding Three-wire System.

for three-phase rotary converters, it may be mentioned that a case sometimes arises in practice in which a special transformer arrangement is necessary. When two or more rotaries are not arranged to be fed (for any special reason) from separate groups of transformers on the alternating-current side, and they are connected to a three-wire network on the direct-current side, then it is necessary to wind each

unit forming the group of (two or three) transformers feeding the rotaries with a multiple secondary winding, as described above, the arrangement being as shown in Fig. 2, illustrating the connections for two machines. That is to say, it is impossible to operate a number of rotaries feeding a three-wire network from common bus-bars on the alternating-current side. The reason is readily apparent from the figure—the slip-ring sides of the machines cannot be *directly* paralleled, owing to the connection already existing on the direct-current side—if they were directly joined a disastrous short-circuit would naturally result. It may be noted in passing that the arrangement of the fuses in the secondary circuits of the transformers shown in this figure [1] (each conductor coming from a slip-ring is fused twice) is a good one, for if one transformer gives out, the service will not be interrupted, for the reason already given above.

There is, however, a certain advantage in using *star-connected* transformers for converters feeding three-wire systems, for by the adoption of this form of connection better balancing can be attained; the secondary neutral points of each group of transformers may be profitably connected to the middle wire, which latter may or may not be earthed. Under these circumstances each rotary would be fed from a separate group of transformers.

The next question arising in connection with the equipment of a rotary converter substation is that of pressure regulation. It is clear that with motor generator substations (whether asynchronous or synchronous), this question hardly comes in, for, as already indicated, the regulation is performed wholly on direct-current machines of standard design, either automatically or by hand, in the simplest possible manner. The conditions are, however, quite different with rotary converters, because the pressure on either side is practically totally independent of the field strength (although not of the field configuration), and consequently, the direct-current pressure cannot be varied by regulation on the fields alone.

There are two commercial ways of regulating rotary converters, each depending upon the same principle, namely, that of altering the pressure on the slip-rings in order to get

[1] This arrangement of fuses for such a case originated with the General Electric Company (U.S.A.).

a corresponding alteration on the direct-current side; as already pointed out, the ratio of the two pressures is practically a constant. The first method consists in varying by hand the impressed pressure on the slip-rings, and can be employed in two ways—either the impressed pressure can be altered by altering the ratio of transformation of the step-down transformers, or it can be altered by means of an "induction regulator." In the first case, the step-down transformers are so arranged in conjunction with a multiple contact switch that either the number of secondary turns, or the number of primary turns, can be altered by hand, thus altering the ratio of transformation; the transformers supplying each rotary have their regulating switches interlocked, so that the turns are cut in or out simultaneously. It is obvious that this method has several disadvantages, the most serious being those of first cost, and difficulty of operation. If the regulation is performed on the primaries, the switches become somewhat difficult and expensive to construct properly, on account of the high pressure of the circuits into which they are connected, while if the regulation is performed on the secondary sides, the expense becomes even greater, on account of the heavy currents to be handled, while the difficulties that arise with the contact surfaces of all regulating switches for heavy currents are well known. But in addition there is the difficulty of arranging such switches to regulate gradually, and to avoid short-circuiting the sections of the transformer winding connected to the contacts of the regulator, as these sections are being cut out or in. Consequently the employment of an induction regulator which does not suffer from any of the above-mentioned defects, and which has but small losses as a rule, will give the best results if hand regulation of the rotaries is asked for or desired.

On account of difficulties connected with insulation, induction regulators should be connected into the secondary circuits of the step-down transformers. As usually constructed, such regulators consist of an iron core arranged in connection with a shunt and series winding in each phase in such a manner, that a movement of the core will decrease or increase the mutual induction between the two windings. Thus if the core is moved inwards, the pressure on the converter slip-rings is reduced, on account of the inductive

action of the shunt winding on the series winding, while as the core is moved outwards, the effect of the shunt coils on the series coils becomes less and less, until at the end of the travel of the core, the pressure on the slip-rings is practically the full pressure of the transformer secondaries. Such an apparatus is easy and cheap to construct, and very effective in operation, a range of six per cent., up or down, being easily attained; moreover, it can be readily arranged to be operated from a distance, and having no contacts or moving conductors, is unlikely to get out of order.

A modification of the induction regulator, first devised, the author believes, by Mr. M. B. Field, is shown in Fig. 3; it possesses the advantage of being somewhat more efficient than the induction regulator described above. The secondary of each step-down transformer has an extension in the form of some extra turns capable of carrying about 25 per cent. of the full secondary current; these extra turns are connected to a small regulating switch, and to the windings of smaller section of a small auxiliary transformer (with ratio say 1 : 4) as shown. The secondary of the auxiliary transformer is in series with the low pressure circuit, and adds or subtracts a small E.M.F. to this circuit as desired. It will be seen that both the voltage and current can be very readily handled, without undue expense, and, moreover, the supply is not interrupted should the regulating switch get out of order.

The second method of varying the impressed pressure on the slip rings of the rotary, in order to get the desired direct current pressure, is of considerable technical interest. Briefly, it consists in compounding the rotaries, and providing a certain amount of self-induction between the terminals of the transformer secondaries and the slip-rings of the machines, if not already existing, by inserting choking coils in the various leads. The rotary converters, being synchronous machines, operate at a power-factor determined wholly by the field excitation; for an alteration of the latter with a given load on the machines, increases or decreases the power-factor of the alternating current circuits; for each load on the rotary, there is, of course, a certain excitation that will make the power-factor a maximum, in accordance with the well-known "V" curve. Let now the shunt winding on the fields of a rotary converter, arranged

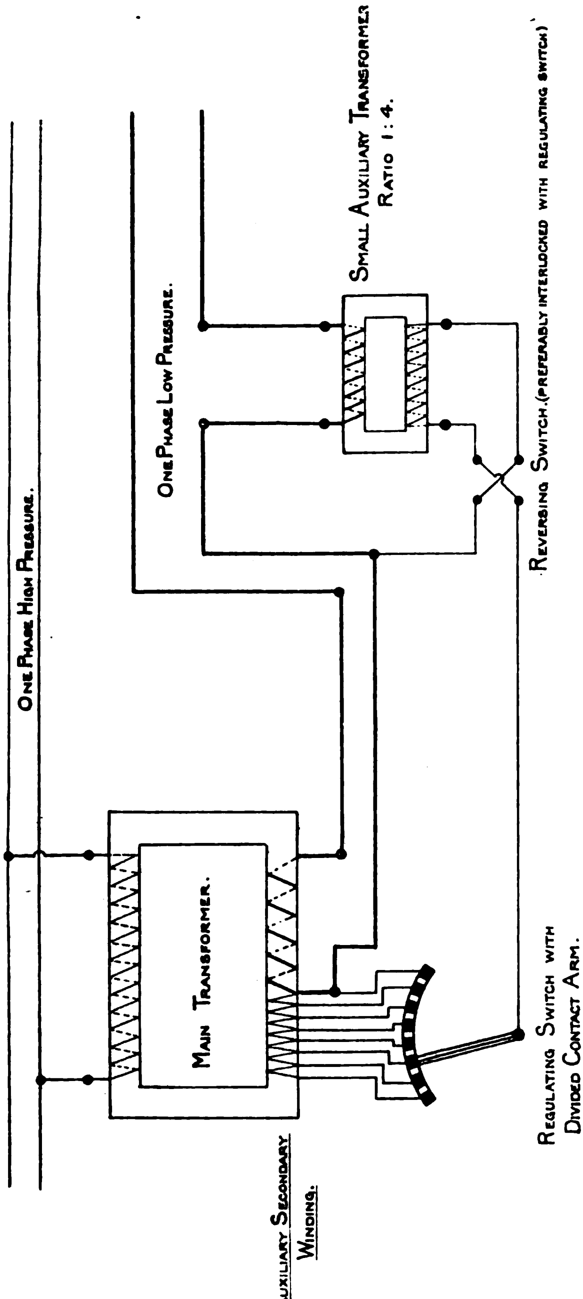

Fig. 3.—Diagram of Connections for One Form of Induction Regulator.

with compound winding, and, if necessary, with small choking coils, be so adjusted that when operating at no load, the machine takes a certain amount of lagging current, say 30–40 per cent. of the full-load current, partly due to the under-excitation, partly due to the reactance in each phase. As the load comes on, the field flux increases, on account of the current in the series winding—that is, the lagging current diminishes, and therefore the impressed pressure increases, producing a corresponding rise in the direct current pressure; this strengthens the fields still more (on account of the shunt winding), until a balance between the two pressures is attained. At full load, the field flux is at its working maximum; the input current will be by this time leading, due to the over-excitation having wiped out the lag produced by the reactance, and the direct current pressure will be raised to the correct value, on account of the increased pressure on the slip-rings. By suitable proportions of the reactance and field windings, excellent pressure regulation can be attained in this way, in a perfectly automatic manner; it is perfectly easy to arrange for the direct current pressure to be over-compounded 10–15 per cent., the actual regulation being nearly as good as with an ordinary over-compounded direct current machine,[1] provided the pressure at the ends of the feeders in the substations is maintained as nearly as possible constant. The only objection to this method of regulation is the influence it has upon the regulation at the feeding points—that is, at the high pressure bus-bars in the substations, for with a number of the latter in parallel, the variation of the power-factor naturally means that the attainment of constant pressure at the ends of the feeders becomes a difficult matter.

The extent to which over-compounding of rotaries can be carried—by means of the above described method—depends mostly upon the rating of the machine with regard to the work it has to do. The limit is of course reached when the current running into the rotary is made to lead (by increasing the exciting current) the impressed pressure by

[1] With a rotary converter of standard design, the change of field flux necessary in order to get the desired amount of over-compounding is much greater than is required with the equivalent direct current machine, for the direct current pressure is not proportional to the field flux but proportional to the impressed pressure on the slip-rings.

90°, for then the inductive E.M.F. of the choking coil (which is 90° behind the current) is in phase with the impressed pressure, and consequently boosts it by that amount; if the current lags behind the impressed pressure by 90°, the inductive E.M.F. of the coil is half a cycle behind the impressed pressure, and diminishes the latter to a value given by subtracting the inductive E.M.F. of the choking coil from the impressed pressure. Neither of these limits are found in practice, for if the angle or lag or lead exceeds certain well-defined values (depending upon the shape of the "V" curve—that is, upon the armature reaction of the machine), the rotary will naturally not carry its rated load. The more liberally rated is the converter, the greater is the range of regulation attained; if the amount of over-compounding required is large (say 15–25 per cent.), the rotary must be chosen large for the work it has to do, although not in this proportion.

Compound wound rotary converters are connected and paralleled on the direct current sides in precisely the same manner as similar direct current machines, equalising bus-bars and switches being used, and therefore the same precautions have to be taken with them should accumulators be used in parallel with the low-pressure feeders.

From what has been said above, it will readily be seen that of the two good methods put forward for regulating the pressure on the direct current sides of the machines, that best adapted for the requirements of lighting work is given by the employment of induction regulators, allowing the pressure to be gradually varied by hand in accordance with the slowly varying load; for traction work, the employment of compound windings (that is, regulation by lagging and leading currents) is preferable on account of the large range of regulation required, and the rapid variations of the load. In some special cases, however, the combination of the two methods will give very good results.

With regard to the starting of rotary converters, all the remarks already made regarding the starting of synchronous motor generators are applicable, as the only difference in this respect between the two classes of machine is that rotary converters are invariably arranged to be self-exciting from their direct current sides. Wherever possible then, such machines should be arranged to be started from the

direct current side, either from the bus-bars, or from an auxiliary asynchronous motor generator. As in the other case, this latter indirect method of starting is far preferable to any other, if no direct current is available at the switchboard.

The next best method to this is that given by induction motors directly coupled to the shafts of the rotaries, while the fourth and last method available (briefly noticed already in connection with the starting of synchronous motors) simply consists in switching the machine directly on the high-pressure lines. As this method has been put forward in connection with several important British schemes, and is in use in more than one of them at the present time, it may not be out of place to devote a few words in its consideration, although in general the method is objectionable.

Any modern synchronous polyphase motor can be started up without difficulty from the high-pressure lines, no matter how constructed; that is, whether the field poles be solid or laminated, whether provided with damping coils or not, &c.—it is only a matter of sufficient starting-current and good mechanical design. This method of starting, as used in connection with rotary converter plants, is as follows: The direct current main and field-switches are opened, only a volt-meter being left across the direct current side, and then the line-current is switched on the slip-rings, either at full or reduced pressure, this latter being arranged for by an alteration in the number of secondary turns on the step-down transformers. Owing partly to the eddy currents in the pole pieces, metal cheeks of field-bobbins, damping coils (where these are used), but principally to the hysteresis lag in the pole pieces, the rotary immediately starts, and is very soon up to synchronous speed. The volt-meter (already referred to) on the direct current side indicates nothing at the moment of starting beyond very feeble oscillations of the pointer, for the current traversing its coils is of course alternating; but as the rotary increases its speed the pointer begins to move backwards and forwards over the scale, its movements corresponding to the rapidly diminishing frequency of the pressure at the direct current terminals; when synchronous speed has been reached the volt-meter pointer will again be

steady, for the current through it is now a direct current. The proper time for putting on the field-current is just before synchronism is reached, and is indicated by the volt-meter; when the beats of the pointer are slowest, that is, just below synchronous speed, when the pointer is moving slowly from side to side over the scale, the field-current can be put in. But it may be noted here that it makes all the difference at which side of the scale the pointer is when the field-circuit is closed; one side is right and the other wrong, depending upon individual circumstances. If the fields have been put on when the pointer is at the wrong side of the scale, then the polarity of the direct current side of the converter will be reversed; with most machines this means that the rotary must be switched out and synchronised again in order to get synchronism at the right pole. In order to make quite sure that the machine has synchronised at the right pole, it is good practice to provide a pole indicator on each direct current panel, so that after the excitation has been put on, the polarity of the direct current side can be checked before the rotary is connected to the direct current bus-bars. Needless to say, a lamp can be substituted for the volt-meter mentioned above across the direct current terminals—it will be bright at the first moments of starting, and also when the neighbourhood of synchronous speed is reached, while between these limits the light will pulsate, and the excitation should be put on when the light is pulsating slowly, the lamp being either bright or dark, according to circumstances.

It will be readily understood that the above remarks regarding the right time to put on the excitation in order to get the right polarity are only applicable to the case of self-exciting machines; if the machines are bus excited, which is very seldom, the converter will pull itself round under protest to the correct polarity with a great rush of current, no matter at which pole the machine has synchronised. A point worthy of note is that even without the exciting current the rotary will come up to absolute synchronous speed, for there is no induction motor action with the rotary converter or synchronous motor. A rotary converter can operate without field excitation, by reason of the heavy lagging currents that would run through its

armature windings under these circumstances; these watt-less currents magnetise the fields to the extent necessary to produce the balancing back E.M.F. of the armature. However, such a method of operation cannot be commercial, for the machines would not carry their rated load; the heavy lagging currents would overload the mains and destroy the pressure regulation of both sides of the system, and the rotaries would spark and hunt. Up to the present, the author has not made any tests on the operation of large rotaries without field excitation, for there is generally little time for such experiments when putting down plant, and, moreover, they may turn out to be somewhat costly; it is an interesting question, however, and it would be of value to know from those who have actually made tests on large units under commercial conditions whether the objections given above are as real as they appear to be. Perhaps with machines having high armature reaction (small air-gaps, &c.) the full load could be carried without the machine stopping, but its performance under these circumstances could hardly be otherwise than poor, quite apart from the bad effect produced on the system; moreover, rotaries with considerable armature reaction have a greater tendency to hunt than those with very stiff fields.

When starting a converter in the manner above described, it is necessary to take certain precautions until synchronism is attained; the series field-windings must be open as well as the shunt, and these latter windings must be opened in five or six places. Otherwise they would break down, due to the large E.M.F. (many thousand volts) induced in them by the alternating flux of the armature. Also, as the starting current will never be less than twice the full-load current, even if damping-coils are used, and will frequently be of the order of three or four times the full-load current, it is necessary to make arrangements for short-circuiting the amperemeters and fuses, otherwise they would be damaged by the overload.

The great objections to the above described method of starting are of course the large starting-current required, and the risk of getting the wrong polarity; the former will wholly upset the pressure regulation of the system, partly on account of its magnitude, but principally because of its low power-factor, while the latter might cause an

accident, and in any case would cause time to be lost when adding a machine to the circuit. For lighting work the employment of this method is absolutely out of the question.

II.—Some Features of Working.

With regard to asynchronous motor generator sub-stations there is practically nothing to be said, on account of the simple character of the equipment and its operation. Two points must be kept in mind however—the sets must be run as fully loaded as possible, and the motor air-gaps must be watched. As the power-factor of the motors will be less than 90 per cent. below three-quarter load, running the machines well loaded becomes even of greater importance than with other classes of electrical machinery, in order to avoid heavy, lagging currents in the feeders. As a matter of fact, it is a good thing to overload such motor-generators (in moderation) before adding a machine to the bus-bars, for then a high power-factor over a wide range of load is assured; the risk is very small, on account of the rapidity with which another set can be started up and put on the circuit. The other point just mentioned—relative to the air-gaps—is of some importance on account of the small clearance in the motors. As with all induction motors, the air-gap length is determined wholly by mechanical considerations, being made as small as possible in order to get high power-factors, it becomes necessary to check it from time to time, in order to make sure that the gap at the bottom has not decreased to a dangerous extent. With large induction motors the gap (iron to iron) will be originally about $\frac{1}{450}$ of the rotor diameter—a 200 B.H.P. motor would thus have a clearance of 0·1 inch with a rotor diameter of $3\frac{3}{4}$ feet, so it will be seen that no considerable diminution of this length can be allowed on account of the magnetic pull, even assuming exceptionally stiff shafts. The stator case of such motors should never be cast with the bed-plate, for if it is separate a thickness or two of metal foil can be inserted between the feet of the case and the bed-plate seatings, by removing which the gap at the bottom can be increased when the brasses have worn

to such an extent that something must be done, and yet not enough to justify their replacement altogether.

With substations employing synchronous machinery, such as synchronous motor generators or rotary converters, several highly interesting and important features of working present themselves. The first is the regulation of the power-factor, and has already been mentioned in connection with rotary converters—the power-factor at any load on the machine can be regulated to the extent necessary in practice by adjusting the field excitation. The curves shown in Fig. 4 gives a good idea of the practical case—they are curves taken for the purpose of this paper from the 650-H.P. Kolben three-phase motor forming part of the motor generator illustrated in Plates I. and II., and whose test curves are given in Fig. 6. The shape of the no-load "V" curve of a synchronous machine is an indication of its performance—a very broad curve indicates, for instance, a motor of but moderate overload capacity, and one that will require but small alterations in the excitation for varying loads; while a very steep curve indicates a machine that must work always with its excitation properly adjusted, otherwise its overload capacity will be small and its parallel running properties inferior; at the same time this latter type of curve is a characteristic of machines with close pressure regulation.

When the machine is loaded the "V" curve alters somewhat with regard to position and shape on account of the increased armature leakage, as indicated in Fig. 5. The amount of this alteration is an indication of the quality of the armature design in this respect—the smaller the alteration in shape, and the less the inclination of the axis *a b* from the vertical, the smaller the pressure drop, and the smaller the increase of excitation necessary for the motor from no load to full load in order that it may work under the best conditions.

Synchronous machines, whether motors or generators, should be so designed that the shape of their "V" curves lies between the two limits mentioned above, for then excellent parallel running, high overload capacity, and good pressure and excitation regulation will all be attained; otherwise one or other of these necessary good qualities will be attained at the expense of the remainder. Running

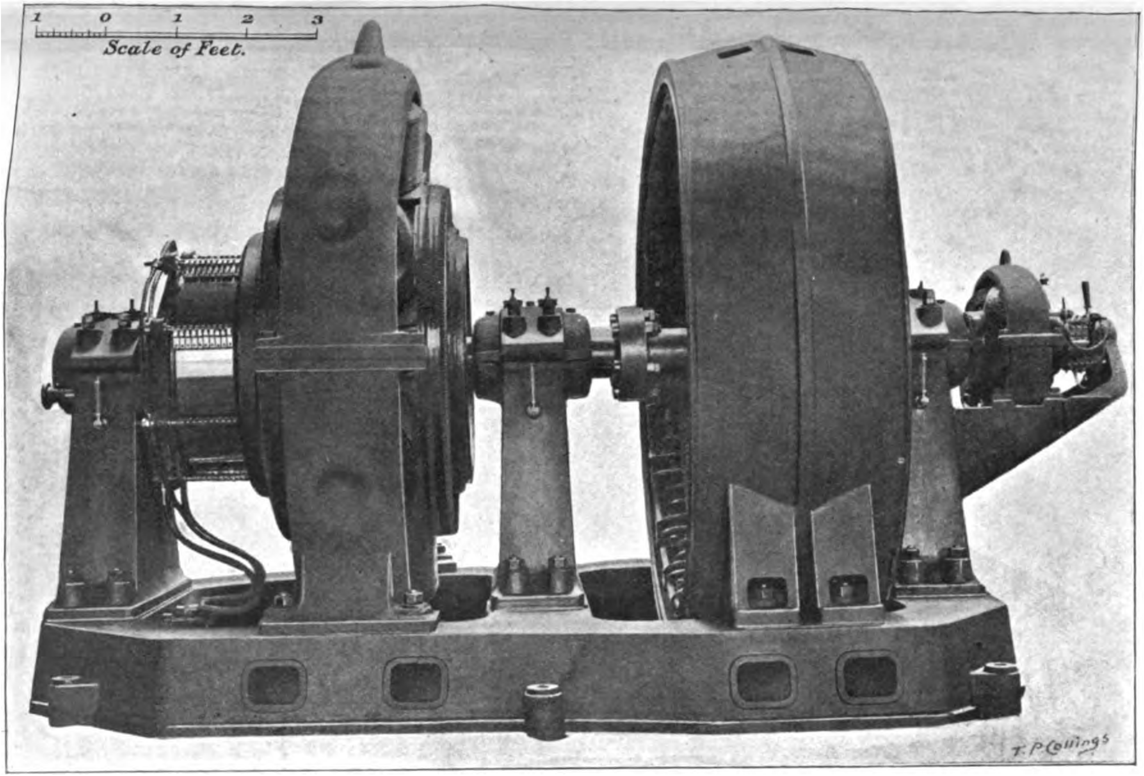

PLATE I.—450-Kilowatt Three-Phase Motor Generator, 240 Revolutions per Minute; 48 Cycles; 3,000–600 Volts.

direct current side, either from the bus-bars, or from an auxiliary asynchronous motor generator. As in the other case, this latter indirect method of starting is far preferable to any other, if no direct current is available at the switchboard.

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With substations employing synchronous machinery, such as synchronous motor generators or rotary converters, several highly interesting and important features of working present themselves. The first is the regulation of the power-factor, and has already been mentioned in connection with rotary converters—the power-factor at any load on the machine can be regulated to the extent necessary in practice by adjusting the field excitation. The curves shown in Fig. 4 gives a good idea of the practical case—they are curves taken for the purpose of this paper from the 650-H.P. Kolben three-phase motor forming part of the motor generator illustrated in Plates I. and II., and whose test curves are given in Fig. 6. The shape of the no-load "V" curve of a synchronous machine is an indication of its performance—a very broad curve indicates, for instance, a motor of but moderate overload capacity, and one that will require but small alterations in the excitation for varying loads; while a very steep curve indicates a machine that must work always with its excitation properly adjusted, otherwise its overload capacity will be small and its parallel running properties inferior; at the same time this latter type of curve is a characteristic of machines with close pressure regulation.

When the machine is loaded the "V" curve alters somewhat with regard to position and shape on account of the increased armature leakage, as indicated in Fig. 5. The amount of this alteration is an indication of the quality of the armature design in this respect—the smaller the alteration in shape, and the less the inclination of the axis *a b* from the vertical, the smaller the pressure drop, and the smaller the increase of excitation necessary for the motor from no load to full load in order that it may work under the best conditions.

Synchronous machines, whether motors or generators, should be so designed that the shape of their "V" curves lies between the two limits mentioned above, for then excellent parallel running, high overload capacity, and good pressure and excitation regulation will all be attained; otherwise one or other of these necessary good qualities will be attained at the expense of the remainder. Running

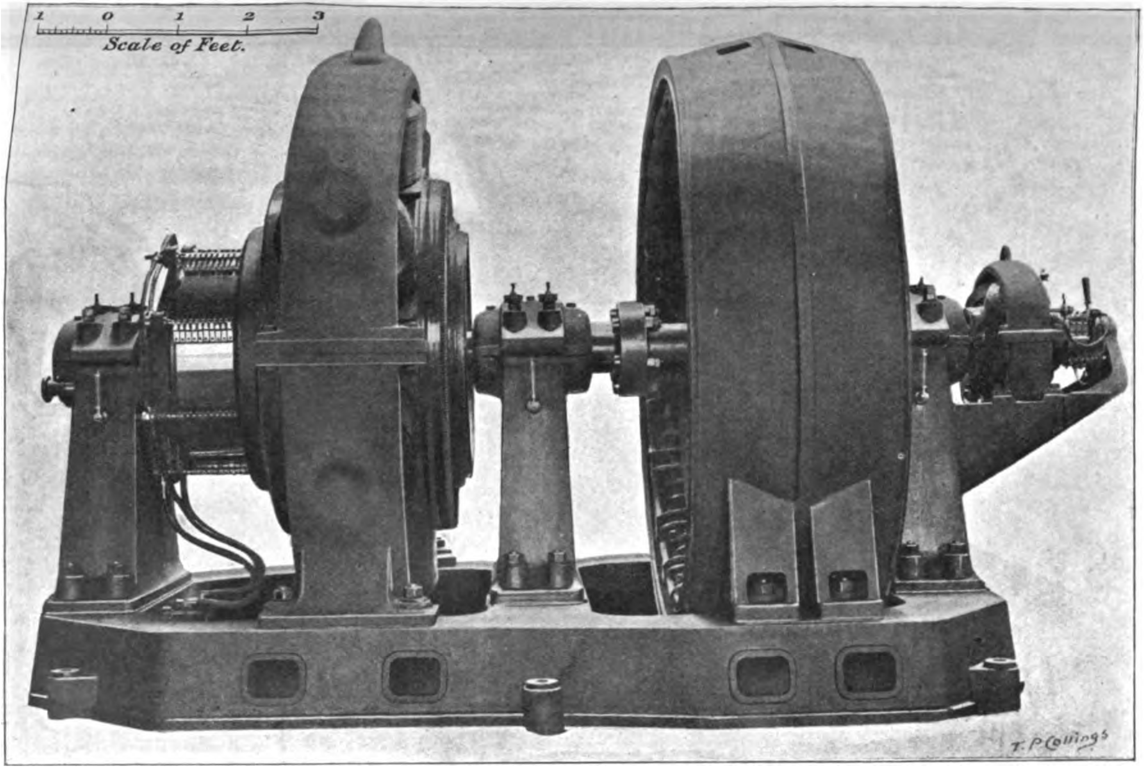

PLATE I.—450-Kilowatt Three-Phase Motor Generator, 240 Revolutions per Minute; 48 Cycles; 3,000–600 Volts.

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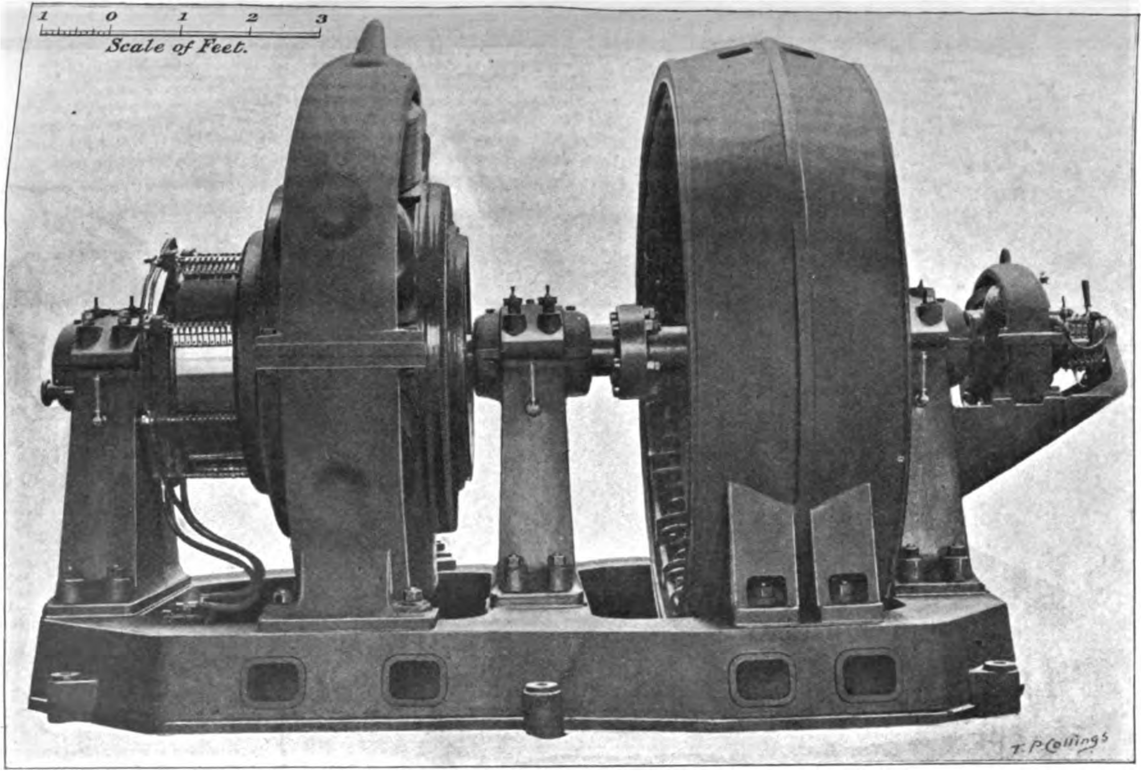

PLATE I.—450-Kilowatt Three-Phase Motor Generator, 240 Revolutions per Minute; 48 Cycles; 3,000–600 Volts.

as generator, then, the full-load drop of the machine at constant speed and excitation should be in the neighbourhood of 5–6 per cent. with 100 per cent. power-factor, and 18–20 per cent. with 80 per cent. power-factor. Better regulation than this is not asked for in modern practice with units of medium and large output; nor is it desirable, especially when substations employing synchronous machinery are fed from them; with better regulation abnormal synchronising currents may pass between the main units, inviting hunting on the part of the rotary

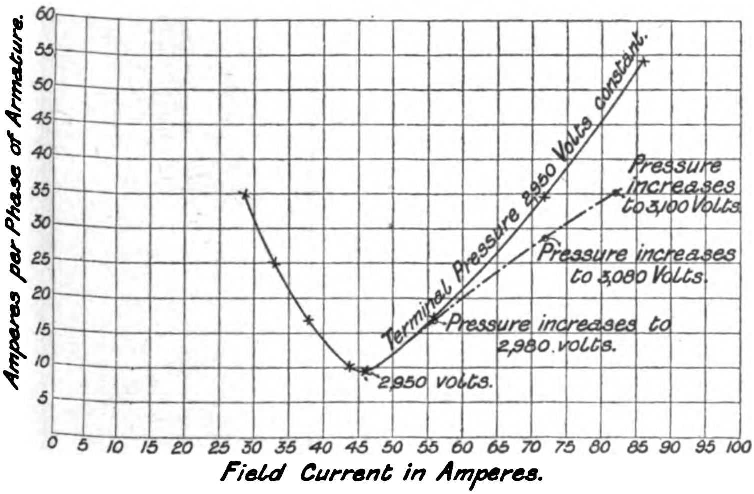

FIG. 4.—"V" Curves for 650 B.H.P. Three-Phase Synchronous Motor. Constant Speed. Constant Load.

converters or synchronous motors. Of course the generators would become at the same time much too heavy and expensive.

Returning to the actual no load "V" curve shown in Fig. 4, it will be seen that when running practically without load, at the constant impressed pressure of 2,950 volts per phase, attained by regulating the bus-bar pressure in the power station, the excitation for the minimum armature current of 9·5 amperes is 46 amperes; a reference to the no-load characteristic of the machine (Fig. 5) shows that with this minimum value of armature current an induced pressure of 2,250 volts per phase is attained. With minimum armature current at a given load, the difference

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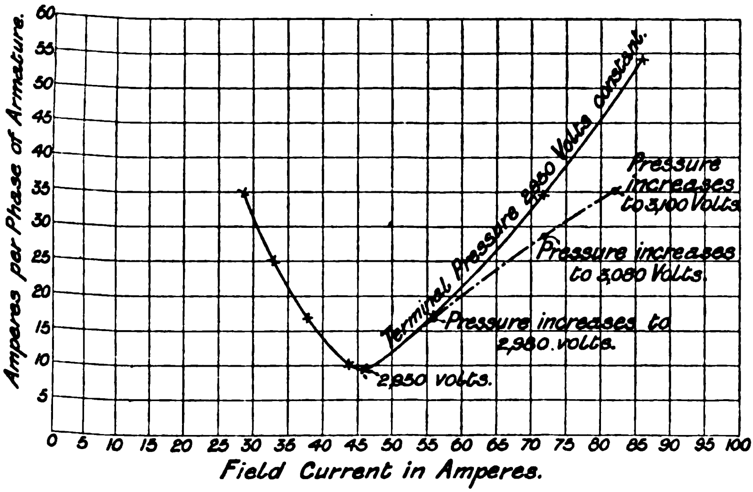

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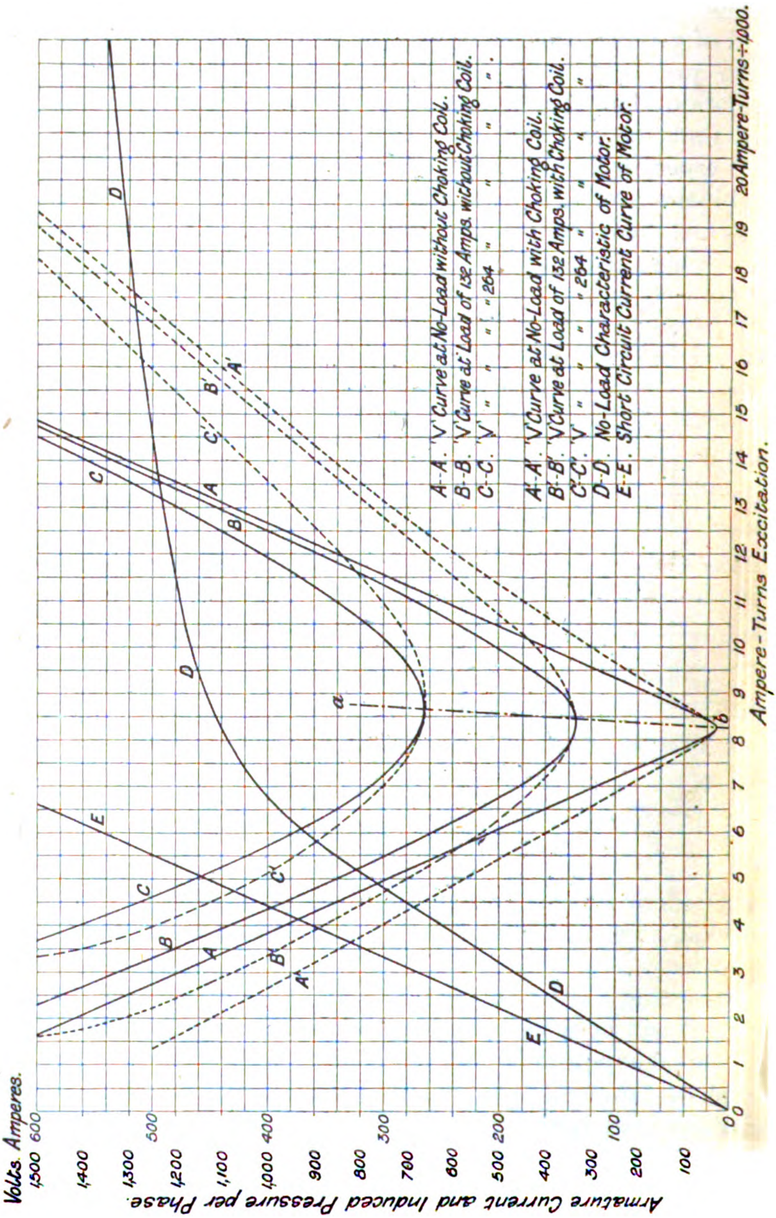

for 725 B.H.P. Two-Phase Sy... Mo... Constant Pressure.

ween the impressed pressure and the back pressure, t is, the difference between 2,950 and 2,250 volts in case, is a measure among other things of the quality he motor from the point of view of pressure regulation; difference between the two pressures under these umstances is due to the impedance of the armature to the pressure and current beats which occur with synchronous machinery—with a constant load and 'ation on a synchronous motor or rotary converter, ack E.M.F. is continually changing its phase relative impressed pressure, a result directly due to variations e angular velocity of the generators, assisted by the entum of the machine itself. At constant impressed ure a decrease or increase of excitation, corresponding decrease or increase in the back E.M.F., causes a fairly l increase of the armature current (and apparent watts) by the motor. At a given load, for any value of the or excitation, a definite value of back E.M.F. takes such ean) position in the vector diagram that the resultant of nd the impressed pressure has a value equal to the edance pressure of the armature. If the excitation be eased above the value corresponding to maximum ver-factor, the impressed pressure at the terminals of motors must of necessity lag behind the current in er that the above-mentioned relations are maintained; the impedance pressure has a constant phase angle tive to the current in a given machine. On the other d, if the excitation is less than the critical value, then impressed pressure must lead the current for the same on.

From the "V" curve, and knowing the various losses constants of the machines, it is possible to make an ximate calculation of the amount of lead or lag that e given to the current. For this 650-H.P. motor g light, the maximum lead works out to be about degrees, while the maximum lag is about 70 degrees. In general, it is not possible to obtain more of the "V" curve than shown in Fig. 4, for, if pushed much farther, the running of the motor becomes unstable, hunting is set up, and the machine drops out of step.

The two legs of an experimentally obtained no-load "V" curve always differ—one is invariably straight, the other

convex (cp. Fig. 4). In this respect, the curves thus obtained from well-designed commercial machines differ somewhat from the theoretical curves, in which, as Steinmetz has proved,[1] one leg is convex, the other concave. This difference between theory and practice in this respect is due to armature reaction and to the influence

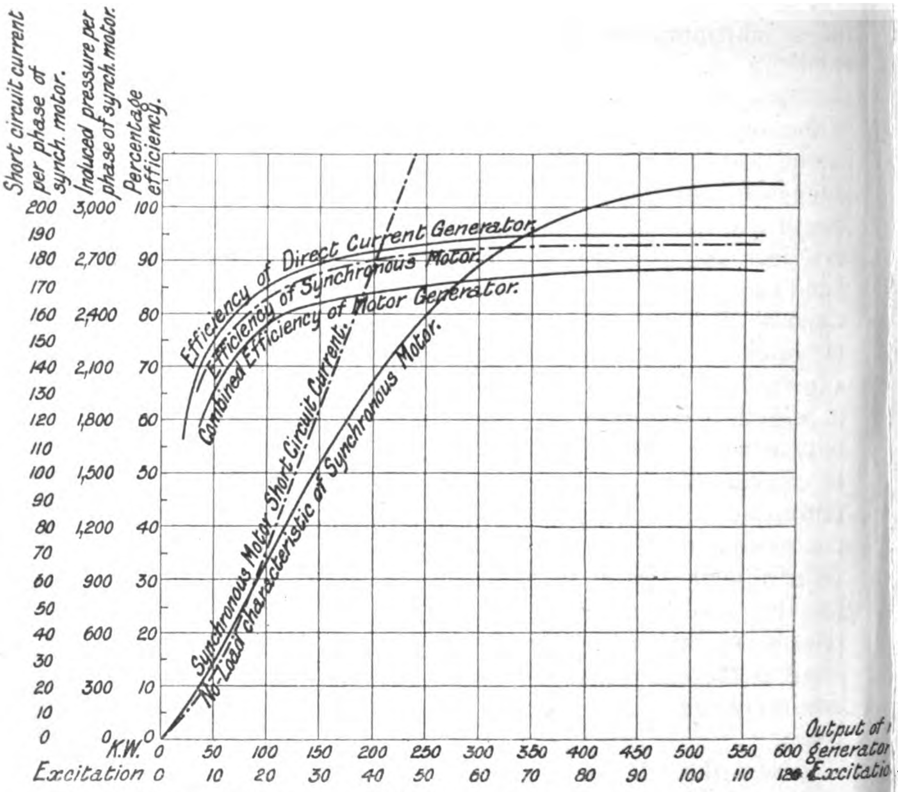

FIG. 6.—Results of Tests on 450 KW. Synchronous Motor-Generator Prague Tramways. Speed 240 Revs. per min. Frequency, 48 Cycles. Volts, 3,000/600–650 per Phase.

of the highly saturated armature teeth when the current is greatly leading or lagging.

The dotted curve to the right of the "V" curve (Fig. 4) illustrates clearly what happens in a transmission plant when the impressed pressure on the synchronous machinery is not maintained constant, but is left to take care of itself;

[1] See *Alternating Current Phenomena*, by C. P. Steinmetz (Whitaker & Co., London and W. J. Johnston, New York).

the pressure at the ends of the feeders rises steadily with increased excitation of the synchronous machines. In this case the 1,000 kilowatt generator supplying current to the motor (through a long three-core cable) had its excitation adjusted once for all at the beginning of the second test, to such a value that the impressed E.M.F. on the motor was the same as before, namely 2,950 volts, *when the armature current had its minimum value.* The excitation of the synchronous motor was then increased, the dotted curve showing the increase of (leading) armature current; the effect of this was to raise the impressed pressure on the motor, that is, the pressure at the ends of the long feeder, from 2,950 volts to 3,100 volts. That is to say, the drop in the feeder (which possessed a considerable inductive drop, owing to the presence of a choking coil in series at the station end) was first wiped out, and then the pressure at the substation end was gradually increased to the extent of over 5 per cent., simply by increasing the excitation of the motor. The frequency of course was constant throughout the tests, and consequently the motor speed also.

A little consideration of the above described characteristic of synchronous motors will show at once how valuable machines of this class become in connection with any transmission plant, on account of their condenser action; it will also show the great superiority of synchronous motor generators and rotory converters over an asynchronous machine for substation purposes, from the point of view of the regulation of the system, and the line losses, &c. Instead of having a lagging idle current throughout the system, wasting energy and impairing the regulation at all points, the power factor of the system can be kept practically at or above unity throughout, the effect of pressure drop in the feeders can be nearly annulled, if desired, and there will be no other losses except those corresponding to the load, unless it is desired to work with a considerable leading current in order to raise the pressure at the substation ends of the feeders, as described.

It is not possible to get a power-factor of *exactly* unity in the circuit, by adjusting the excitation of a motor running light, so as to obtain minimum armature current. That is to say, the bottom of the "V" curve does not mean that the current running into the armature of the motor is in phase

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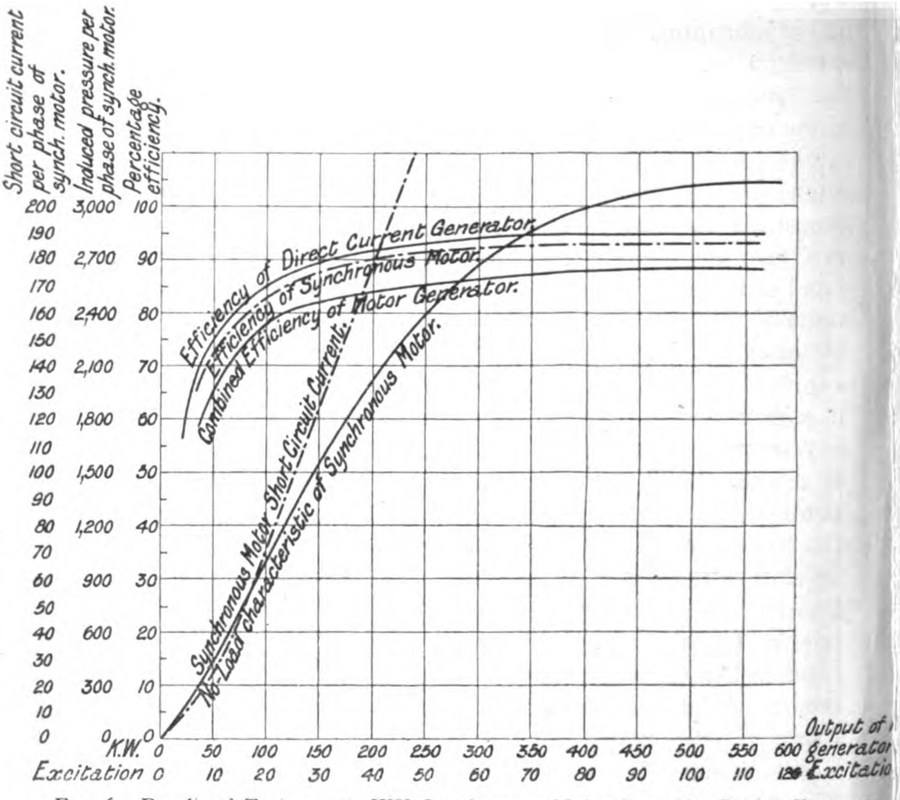

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with the impressed pressure ; it is very nearly in phase, but not quite, owing mostly to the difference in the E.M.F. waves of line pressure and motor pressure. Large synchronous motors, when well loaded, and if of good design, generally have full load power-factors of 96 to 98 per cent. when working at the excitation corresponding to minimum armature current.

In practice the utilisation of the phase rectifying properties of synchronous (motor) machinery works out as follows. With rotary converter substations, if the machines are compounded, the power-factor of the system will be nearly unity at about half load, the current lagging somewhat before this, and leading afterwards, in accordance with what has already been said in this connection on page 718 ; at full load the drop in the feeders supplying the substation will be considerably reduced. If the rotaries are shunt wound, or if synchronous motors are employed, the field current is so adjusted that the power-factor is highest at about three-quarter load—at both lighter and heavier loads, the current is somewhat out of phase, the minimum power-factor being say 0·95. Or, if heavy overloads are expected, the machines had best be somewhat over excited at full load in order to increase the impressed pressure, especially if synchronous motors, for the overload capacity is thereby increased, the torque being proportional to the square of the impressed pressure. Thus with a synchronous motor generator substation, if the motors are well designed, it is not necessary to alter the excitation continually with the load ; but two adjustments between no load and full load will be generally advisable, in accordance with what has been said above. The small amount of field regulation required in practice with well-designed synchronous motors is well illustrated by Fig. 5.

If a substation equipped with synchronous machinery has to work in parallel with large inductive loads, such as large induction motors, or another station arranged with asynchronous motor generators, it is as well to arrange for the lagging current to be balanced by the synchronous machines. That is to say, the synchronous motors or rotary converters will be liberally designed, in order that they may carry the balancing leading currents (and increased excitation) in addition to the load.

A word or two may be said here regarding the overload capacity of the three classes of substation equipment. With motor generator substations, what may be termed the permanent overload capacity depends only on the direct-current machines, that is to say, it will be in general about 20 per cent. for two hours, the position of the brushes on the direct-current machines remaining unaltered. With rotary converters the corresponding overload capacity is of course greater, and in practice is determined as a rule by the commutator heating. The commutators of rotary converters invariably have peripheral speeds bordering upon the upper limit of good practice—say 3,000 feet per minute—consequently an overload of about 30–40 per cent. for two hours is about as much as can be furnished without overheating the commutators. If it were not for this, and provided the field system was well over-excited, the overload capacity could be safely taken to be 50–60 per cent. for the time stated; it would be determined by the permissible safe temperature rise of the armature coils and step-down transformers. It is hereby assumed that these latter are artificially cooled by means of cooling pipes in the oil, or by forced draught, the normal temperature rise being 35° C., conforming in these respects to good modern practice.

What has been called the "permanent overload capacity" above is however really of minor importance in practice, for the plant would not be subjected to such treatment except when being taken over, or when a breakdown occurs. The important point, particularly with substations feeding tramway or railway systems, is the momentary overload capacity, that is t say, the effect of short circuits of brief duration has to be considered.

Regarding this point, it may be at once stated that the three classes of equipment are perfectly satisfactory, and moreover, from this point of view, there is but little to choose between them. Well-designed asynchronous and synchronous motors and rotary converters fed from a well-designed power-station will all stand overloads of 100 per cent. for a few seconds without falling out of step, the two classes of synchronous machines behaving in a very similar manner to the asynchronous machines. This is about the safe limit of overload capacity for standard machinery—the short circuit, or whatever it may be, causing the momentary

overload is naturally unexpected, and consequently the plant as a rule cannot be stiffened up by field regulation, to stand more, or to stand this amount for a longer period, with safety. It does not follow that the machines will drop out of step, although asynchronous motor generators designed for high efficiency would probably pull up; the synchronous motors or rotaries would generally become unstable in their running, and start hunting.

With regard to the falling out of step of synchronous machinery, it may be observed here that once this happens the inherent tendency of a machine to pull itself in again is determined by the torque it can exert in a very short time, namely, half a cycle; consequently, if there is any load on the machine, it must necessarily pull up.

Should a momentary short circuit pull out the circuit breakers in the power-station, or otherwise break the circuit on the alternating current side of the converting machinery, it is always necessary to give the substations time to shut themselves down, rather than immediately replace the circuit breakers, while the converting machines are still turning. Under these latter circumstances even induction motors will not run up to speed, while the synchronous machinery forms simply a pulsating short circuit across the mains, a synchronous motor or rotary acting alternately as motor and generator relative to the transmission lines, and gradually pulling up. Before this happens, the circuit breakers will be out again; apart from this it would in general be impossible to keep in the circuit breakers on the direct current sides of the converters.

One of the most important questions to be considered in connection with the design and operation of a synchronous substation equipment is that of parallel running. The converting machines have not only to run perfectly in parallel with one another, but the various substations have to run perfectly in parallel with one another, and with the power-station also. In most modern installations this requirement has been easily attained, but in others great difficulties have arisen, and have had to be got over at great cost before satisfactory working over the whole system was attained. It is, therefore, of interest to discuss as briefly as possible the leading features of the question.

With a rotary converter substation, for instance, unless

every detail of the system is thoroughly well designed, from the engines in the power-station to the rotaries themselves, there will be trouble with regard to the parallel running of the machines—that is to say, they will hunt. The term hunting, as applied to synchronous machinery of this character, means that while running at synchronous speed (as measured by a tachometer), the machines oscillate between themselves—that is, during a revolution they increase and decrease their angular velocity above the mean velocity, corresponding to exact synchronism, causing the armatures to swing backwards and forwards from a fixed point, (in a precisely similar manner to the swing of a pendulum), while still keeping in step. The effect of this is to cause the pressure on each side of the rotary to fluctuate more or less badly, so that working at constant pressure on the direct current sides becomes impossible. Once a rotary has started hunting, unless the small oscillations are immediately checked, they will invariably continue to increase in amplitude until the armature swings over and loses synchronism.

The running performance of synchronous (motor) machinery depends so much upon the variations in the velocity of the power-house engines during a revolution, and upon the oscillations set up by the engine governors, &c., that if these variations or oscillations exceed certain well-defined limits it becomes impossible to operate the substations successfully. That this must be so becomes clear when it is considered that every variation in the supply frequency, (during an engine revolution), has to be taken up by the substation machines against their own momentum, with the result that if the armatures get accelerated or retarded to any extent from this cause, hunting is bound to occur, and operation of the plant becomes impossible until the engines are working properly. This is a case in which the hunting of the converters is due to a well-defined cause outside the machines themselves.

But although hunting may be sometimes caused in this way, the speed variations in the engines are by no means a necessary accompaniment to it, for it may be started in a variety of ways (of which engine pulsation is one), and then increased by the action of the machines themselves. This latter case—that of hunting on the part of the rotaries

when the power-house engines are entirely suitable—is of considerable interest.

A working explanation of what happens in this case is as follows:—Let a slight oscillation be set up between the machines, by any little thing that may occur with the most perfectly designed plant it is possible to have, such as a sudden large change in the load, a short circuit, or faulty setting of the brushes on one machine, or an engine hunting in the power station (due to a small mishap, &c.)—this slight oscillation is accompanied by a weakening and distortion of the field flux of the converter. The mere fact of there being an oscillation implies field distortion, for a fixed point on the armature during the swing is either a little ahead of, or a little behind, the true position (corresponding to exact synchronism) it should have at this instant. This means that the machine is acting either as a generator or motor, taking either a leading or a lagging current from the lines, and shifting the diminished field flux to one or other of the pole horns. The armature will now try to follow this change of field configuration, taking a large current in the reverse direction in order to do so. But this change of current immediately distorts the field flux in the opposite direction to a much larger extent, and the armature again tries to swing to the new position. Thus each oscillation of the armature gets larger and larger, and the field distortion is greater and greater, until finally the flux from the poles gets swept nearly entirely away from the pole faces to the pole horns and gaps between them, the machine eventually swinging out of synchronism. During these oscillations the converter is acting alternately as generator or motor, giving up to, or receiving power from, the other converters in parallel with it, giving them in this way alternately a push and a pull at the wrong times, causing them to start hunting also. The combined effect of the various machines in parallel is to increase the hunting originally set up, and if other substations are in parallel, the oscillations may also be taken up by the machines in these, the combined effect perhaps even reacting on the generators in the power-station, causing them to start oscillating also. It is thus obviously necessary to provide means of checking the oscillations while they are still small, otherwise they will get out of control and spread over the whole system.

The sparking and flashing over which frequently takes place at the commutators of rotary converters when hunting is directly due to the pulsation of energy, and to the field distortion and fluctuation, for good commutation under these conditions naturally becomes impossible. The distortion of the field is really the root of the whole matter, and if this is prevented, or reduced to a minimum, hunting cannot occur.

That the whole magnetic system of a rotary converter that is hunting is in a very disturbed state is made readily apparent during working. For instance, a spanner held in the hand between two field poles is strongly attracted with variable force. As a matter of fact, even when the machines are working properly there is a certain amount of field pulsation, it being sometimes easily possible to estimate the speed of the power-house engines from the small, quick movement of the pointer of the field amperemeter.

There are certain conditions of working which tend to cause hunting, or which make hunting worse should it be set up. An example of the former is difference in the form of the E.M.F. waves of generators and rotaries, which is in itself sufficient in some cases to start hunting, but such differences are, as a rule, not sufficient to give rise to serious trouble. On the other hand, machines with strong armature reaction, or working much under excited, are more liable to hunt than those with strong fields, because the magnetic flux is more readily distorted. For this latter reason it follows that over-excitation of the rotaries is a condition favourable to good operation. Again, the momentum of the converters should be kept as low as possible, for this apparently indirectly assists hunting, and in any case impairs the action of any device that may be used for damping the oscillations in their early stages. Some engineers state that hunting on the part of the substation plant is increased by the impedance of the lines, but the author has not as yet found this, and considers that a moderate amount of self-induction in the lines is directly beneficial. Capacity in the feeders, on the other hand, does appear to have some influence. In practice, however, it is generally difficult to separate the causes that assist hunting from one another. The main cause will generally be found to lie with the engines, and when this is removed, or when

the effects of field distortion set up by it are neutralised, the troubles generally disappear.

Synchronous motor generators are far less likely to hunt (with a given generating plant and transmission system) than rotary converters. This is because there is considerable armature reaction in the synchronous motors, which tends to damp the pulsations in the armature current should hunting be set up, and also because the field system is fed at a steady pressure, which is totally independent of the pressure at the ends of the feeders. But with unsuitable engines synchronous motors will hunt badly, the pressure on the direct current side being practically unaffected thereby, which is a point to be noted. The characteristic pulsations in the feeder pressure will, of course, occur to just the same extent as with rotary converters.

From what has been said above, it will be seen that to ensure the perfectly satisfactory operation of synchronous substation machinery, two points must be attended to. The first is to take great care with the selection and operation of the generating and substation plant, particularly the former, so that the tendency to set up hunting will be as small as possible; and the second is to provide means for getting rid of the hunting—that is, damp the armature oscillations in their earlier stages—should it be set up.

Some considerations relating to the design of the generating plant will be given later, while regarding the means for damping the oscillations a few remarks may be made here. As these oscillations are actual speed variations, it is evident that it might be possible to reduce them considerably by mechanical means, but the cost of devices for this purpose would be out of the question, to say nothing of other objectionable features. On the other hand, the oscillations are accompanied by, and intimately connected with, the field distortion as described above, and consequently if this distortion could be done away with, hunting would be prevented. Happily, very simple and effective means are available for suppressing the distortion of the field flux. All that has to be done is to fit the synchronous motors or rotary converters with "damping coils." This device, which is one of the many excellent ideas in polyphase working which have reached this country from the Continent *viâ* the States, is of the greatest value in such cases, and rarely fails to stop

the worst cases of hunting. All that has to be done is to bridge the poles of the synchronous motors or rotaries from

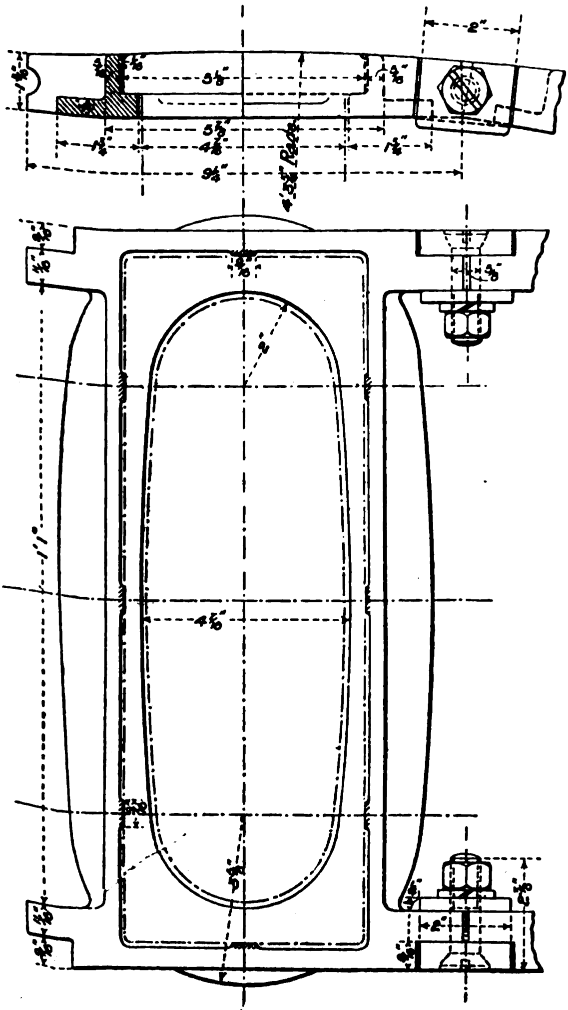


FIG. 7.—Combined Damping Coil and Field Coil Support for 725 B.H.P. E. and H. Synchronous Motor. Speed, 212 Revs. per Min.; Frequency 60 Cycles; Peripheral Speed, 5,500 ft. per Min.

horn to horn by copper plates or strips. These will have the effect of wiping out the distortion of the main magnetic flux, and therefore damping the armature oscillations, by

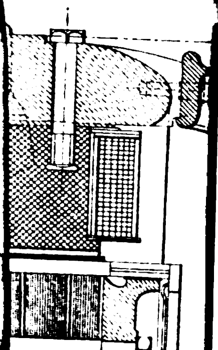
reason of the eddy currents produced in them by the flux due to the large leading and lagging armature currents—that is to say, as soon as the armature of the rotary or synchronous motor starts swinging, accompanied by the field distortion described above, the opposing flux produced by the eddy currents in the copper strips blows it away from between the pole-horns, and the oscillations are thus damped out magnetically directly they commence to form. It will be observed that the damping coils produce their effect just where it is wanted, namely, between the pole-horns. It is relatively of little use to put damping coils *round* the pole pieces; the metal is wanted at the horns of each pole, and between the horns of adjacent poles.

The dimensions of the copper strips connecting the poles of the motor or rotary can be varied within wide limits without making much difference to the damping action. The losses in them with actual rotary converters are found to vary from 0·5 to 1·5 per cent. of the output of the machine, depending upon circumstances. An idea of the actual dimensions of damping coils used in practice is given by Fig. 7, which illustrates the gun-metal damping coils, combined with the outside cheeks of the field bobbins, for the synchronous motor of the 500-kilowatt two-phase motor generator shown in Plates 3 and 4. The damping strips bridging the pole-horns of the rotating magnet wheel are cut away centrally, partly because the centre portion is not very effective, but principally in order to prevent the ventilation of the magnet wheel and armature being impaired.

As rotary converters will hunt upon slight provocation, such machines should always be fitted with damping coils, whatever the nature of the engines. They need only be used with synchronous motor generators when the power station engines are badly designed, unless lighting is done from the same feeders. In this case it will generally pay to use them. With water-power plants they are generally unnecessary for either class of plant. On the other hand, if the engines are very bad they should be used on the generator field poles as well, where they will have a precisely similar effect (for the case is similar), and will reduce the synchronising current between the generators practically to zero.

One result of hunting in the substations is that the current in the high-pressure feeders pulsates. As a matter

GENERAT



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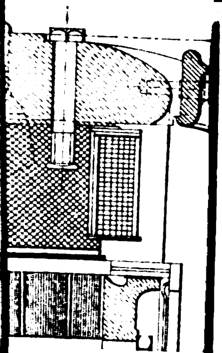

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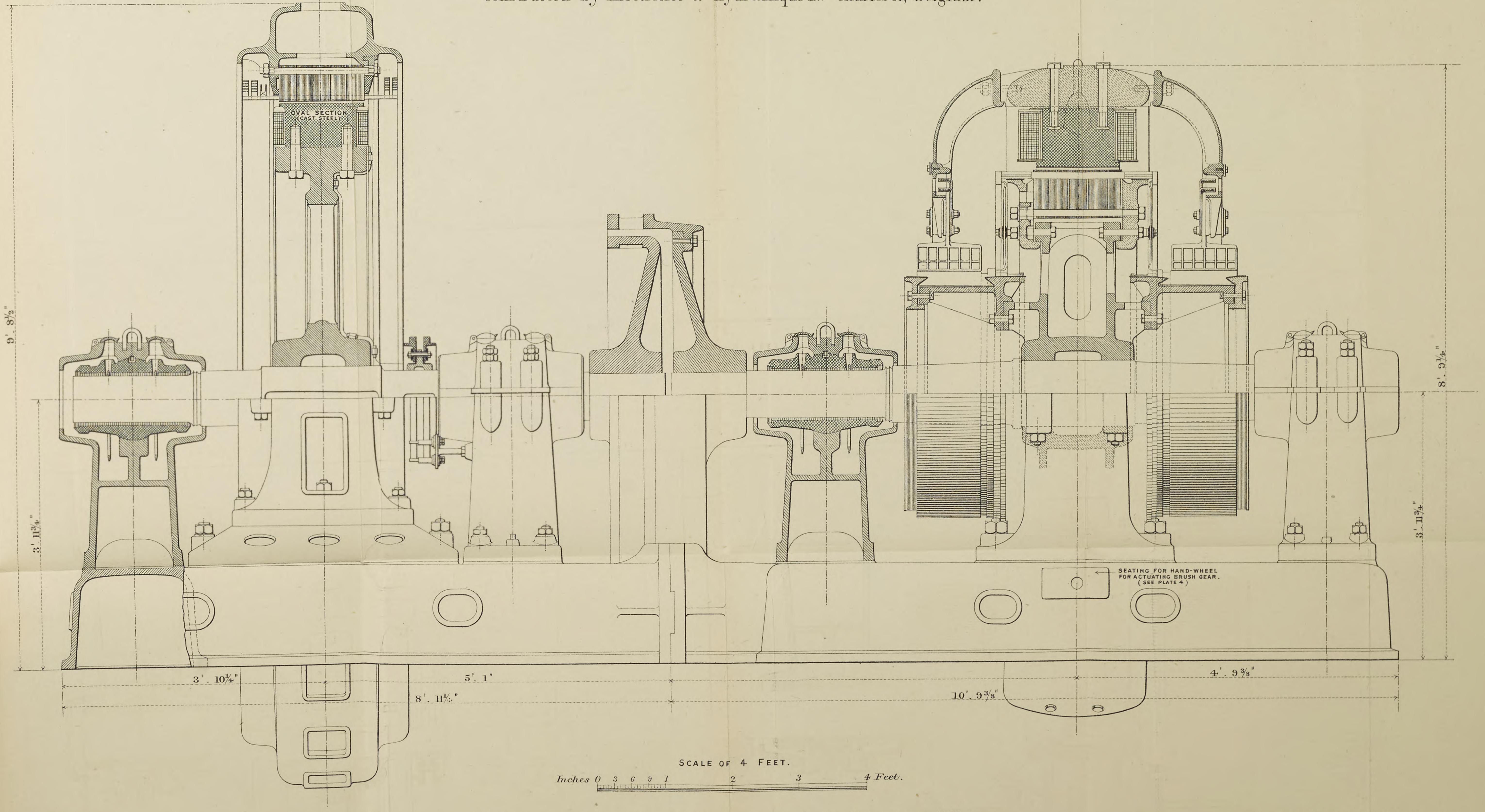
One result of hunting in the substations is that the current in the high-pressure feeders pulsates. As a matter

FRONT SECTIONAL ELEVATION OF 500 KILOWATT TWO-PHASE SYNCHRONOUS MOTOR GENERATOR. *Plate 3.*

MANCHESTER SQUARE SUB-STATION, LONDON.

SPEED 212 R.P.M. – FREQUENCY 60 CYCLES – VOLTS 1100/200 – 230.

Constructed by Electricite & Hydraulique Ltd. Charleroi, Belgium.



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of fact, in accordance with what has already been said above, these pulsations occur to a certain extent even when hunting is absent, for they are due to the inherent properties of the machines. This pulsation of current in the feeders, accompanied as it is by corresponding pulsations in the pressure, become highly inconvenient if lighting has to be done directly from the feeders in question. The case might arise, for instance, with a transmission and distribution by three-phase currents for lighting and power, combined with a direct current distribution from substations for the tramways. The remedy, first put actually into practice by Mr. Kolben in connection with the electricity supply for the town of Prague, is to insert choking coils in the high-pressure substation feeders, these being of the three-phase type with common core for three-phase working. The output of the choking coil in circuit with each feeder should be about 3 per cent. of the maximum power absorbed by the synchronous machinery connected to it. Thus in Prague, for instance, in one case a 900-kilowatt substation (with 450 kilowatts in reserve) is connected by a three-core cable to the power house three and a quarter miles away, a three-phase choking coil of 25 kilowatts, having an air gap adjustable (by packing pieces) to about 0·375 inch, being in series with it. The principal dimensions of this coil are given in Fig. 8. The fluctuation in the pressure at the substation end of the feeder when working under the worst conditions (no load) is about 3 per cent. with the coils cut out, and nothing that can be detected when they are in circuit. When the coils are in use, the synchronising current between the two synchronous motors of 650 B.H.P. is 8 to 10 amperes with an input of 60 amperes, and 5 to 10 amperes at full load (100 amperes), but when they are cut out the motor synchronising currents are more than double.

At another substation two and a quarter miles from the power station, having a smaller equipment, namely, two 180-kilowatt synchronous motor generators (one as reserve), there is no synchronising current at all between the 260 H.P. motors as long as the choking coils are in circuit. The current in this feeder when the sets are well loaded is as steady as it would be if asynchronous motors were in use.

The use of choking coils in the substation feeders has

proved to be of the greatest value in Prague, because all the lighting and motor work is done from the same three-phase mains, the direct current substations serving only for the tramways. The pressure variation at the 900-kilowatt substation, that is, on the terminals of the 650 B.H.P. motors, only varies between 2,900 and 2,980 volts, and does not change with the load, because the synchronising currents

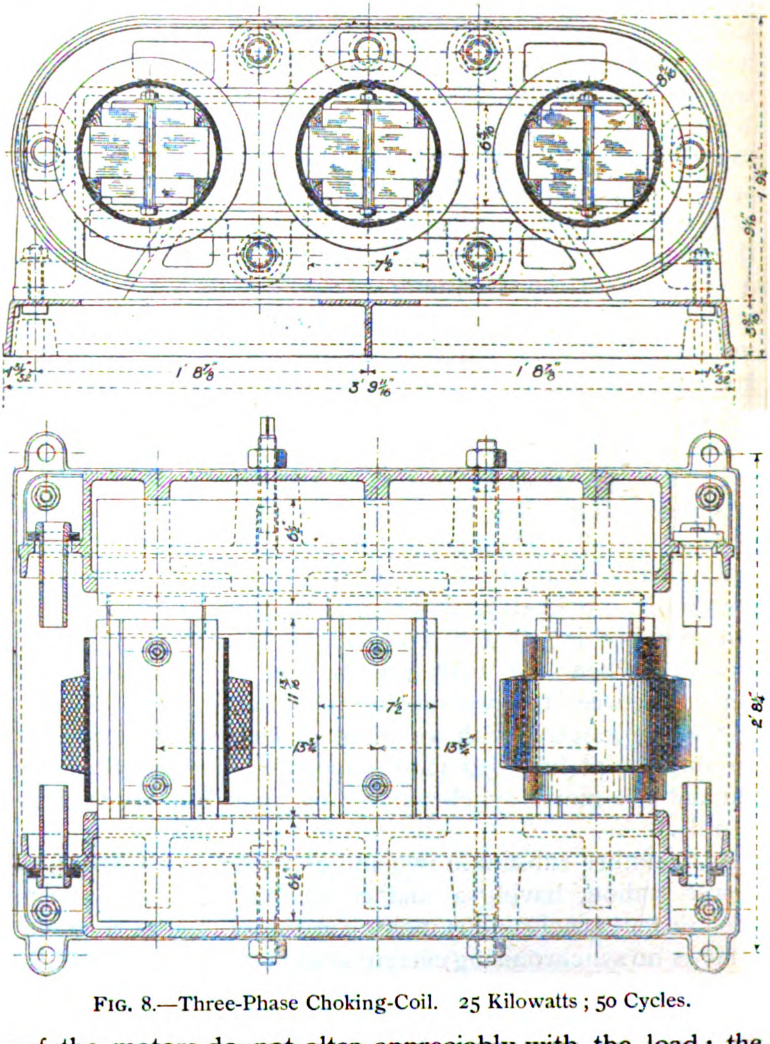

FIG. 8.—Three-Phase Choking-Coil. 25 Kilowatts; 50 Cycles.

of the motors do not alter appreciably with the load; the excitations of the motors are hardly altered, being 62 amperes

End Sectional Elevations of 500 Kilowatt Two-Phase Synchronous Motor Generator.

MANCHESTER SQUARE SUB-STATION, LONDON.

SPEED 212 R.P.M. – FREQUENCY 60 CYCLES – VOLTS 1100/200 – 230.

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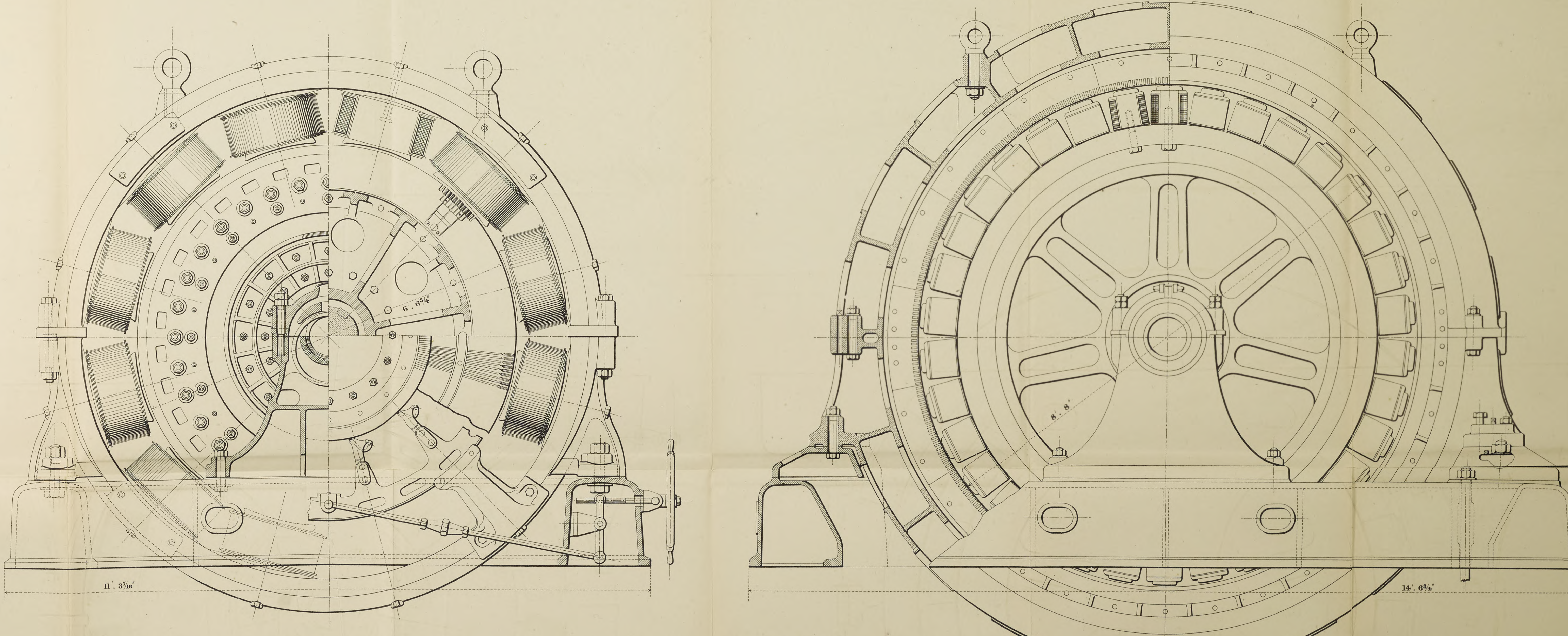

SCALE OF 4 FEET.

Inches 0 3 6 9 1 2 3 4 Feet

A. C. EBORALL.

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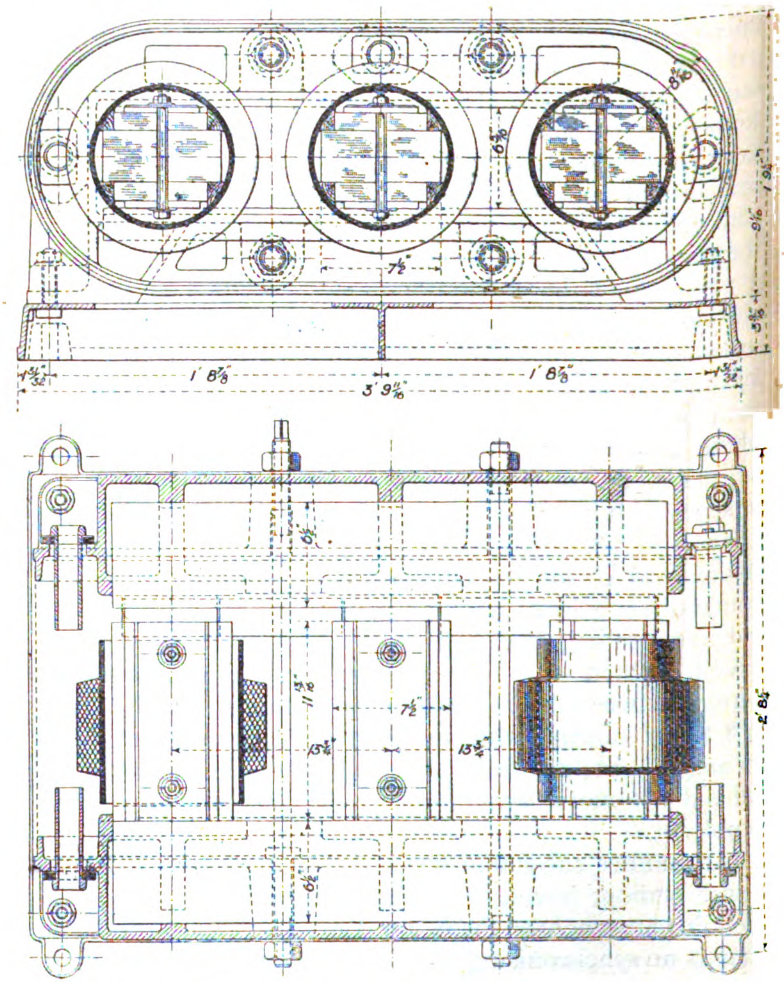

FIG. 8.—Three-Phase Choking-Coil. 25 Kilowatts; 50 Cycles.

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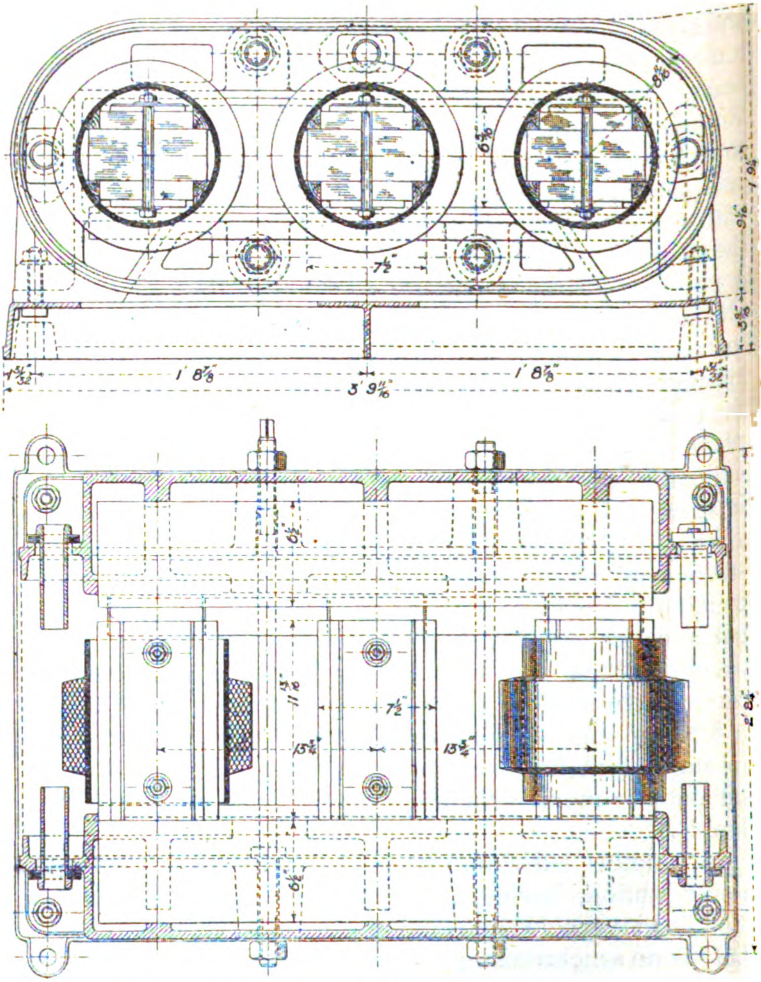

FIG. 8.—Three-Phase Choking-Coil. 25 Kilowatts; 50 Cycles.

of the motors do not alter appreciably with the load; the excitations of the motors are hardly altered, being 62 amperes

at no load, and 65–70 amperes at full load, the latter figure being attained when heavy momentary overloads are expected, such as at holiday times, when extra car services are run, &c.

The town of Prague (250,000 inhabitants) has one of the best combined services in Europe. The whole of the very extended lighting, power, and tramway service is carried out from a single power-station

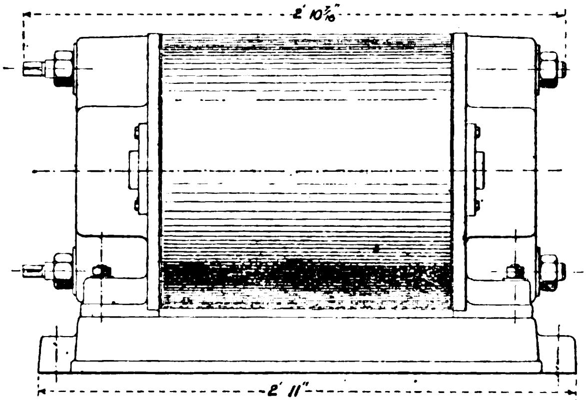

FIG. 8 (*continued*).—Three-Phase Choking-Coil. End Elevation.

of 15,000 H.P. ultimate capacity, 5,000 H.P. being now at work. There are about 26,000 8-c.p. lamps at present connected directly to the three-phase mains, as well as 400 kilowatts of public lighting and many induction motors, including several of 100 B.H.P.; about one hundred and sixty American-type cars are supplied from the substations at 550 volts, the average output for traction being about 1,300 kilowatts at the present time. Every consumer having more than sixteen 8-c.p. lamps connected up has the three conductors taken to his premises; three-phase transformers in street boxes are used in all cases. The declared pressure is 120 volts at 48 cycles, and the minimum and maximum pressures any consumer gets at any time of the day are 118·5 volts and 123 volts respectively.

The electric lighting, power, and traction services in Prague form a combined municipal undertaking of assured financial success, although but recently set to work. The transmission and distribution is carried out with three-phase currents throughout, with perfect success, balancing troubles (so much feared in this country by those unacquainted with the practical working of three-phase systems) being entirely unknown.

Great care has been taken by Mr. Kolben with regard to the design of the power-station engines at Prague, as the successful operation of such a combined system depends first of all upon their good qualities. With regard to

governing, they are practically faultless, while the speed variation in one revolution (that is to say, the total variation, above and below the mean speed) does not exceed 1 in 250; the engines are of the triple expansion horizontal two-crank type, rated at 1,000 B.H.P. at 90 revolutions per minute, the flywheel effect[1] being 12,700 foot^2- tons, in order to attain this.

The use of choking coils in the substation feeders may perhaps be thought objectionable, on account of the increased losses and pressure drop brought about by their use, but a little reflection will make it evident that this disadvantage is but trifling, and far more than counterbalanced by the advantage of doing away with all pulsations in the pressure. The full-load loss in a large choking coil is not more than about 3 per cent., and the inductive drop under usual working conditions, say 4 per cent. With the above-mentioned 25-kilowatt choking coils, the full-load loss is only 800 watts, and the pressure drop 60 volts (assuming the motors to be working at minimum excitation), and consequently their influence in impairing the efficiency or regulation of the system is insignificant. Naturally, it is far better to place the required reactance outside the generators than to design the latter with large reaction and consequent drop.

From what has been said above, it will be readily seen that if rotary converter or synchronous motor generator substations have to be supplied from a steam-driven power station, very great care must be taken to prevent oscillations in the relative motions of the generators running in parallel, with the consequent interchange of synchronising currents. These oscillations can be started by the natural variations in the turning moment during the revolution, or by the after-effects of a bad parallel, or short circuit, &c., and are assisted by field distortion, by insufficient armature impedance, by quick-acting governors, by very heavy magnet wheels, and of course by faulty design, such as short connecting rods, defective steam distribution, want of balance, &c. Given well-designed engines, it will generally

[1] By "flywheel effect" is to be understood the very convenient Continental definition (not the kinetic energy of the rotating magnet wheel), namely, $W \times D^2$, where W = the weight of the wheel in tons, and D = mean diameter of the flying masses in feet.

be found that the trouble, when it is present, is due entirely to the governors assisted by the momentum of the magnet wheels and by the attempts of the generators themselves to attain their proper phase relations; the cure for it consists in adjusting the governors in such a manner that they are absolutely unresponsive to very quick variations in the speed.

The reason is probably as follows. If the governors are extremely sensitive, they will endeavour to compensate for the unavoidable momentary speed variations due, for instance, to the steam impulses; as the speed increases during the impulses the cut-off will be earlier, while as the speed falls between the impulses the cut-off will be later. But the governor will overdo this, as is well known: it admits, for instance, more steam than is wanted to bring up the speed, causing the engine to accelerate, and *vice versâ*. —and in this matter it is helped by the momentum of the magnet wheels. What appears to happen is that a small relative oscillation of the revolving magnet wheels is started from unavoidable causes—that is, it is brought about by variations in the turning moment—which would, under ordinary circumstances, be completely taken care of by the momentum of the magnet wheels. Owing, however, to the sensitive governors of the engines in parallel, the oscillation is not only kept going, but is actually increased by the lag of the governors in conjunction with the action of the periodic puffs of steam admitted to the engine cylinders by them. Of course these oscillations of the moving parts of the generators cause phase displacements between the respective E.M.F. waves, which may be sufficiently large to cause the machines to become unstable. In any case, large synchronising currents will pass between the machines, and the oscillations reappear in the substations, starting hunting of the motors or rotaries, as above described.

It is found in practice that the amount of the relative motions of the generators can be reduced to practically nothing if the governors can be prevented from responding to slight quick changes in the speed, and this, of course, is a matter of suitable governor dash-pots. Each engine governor should be fitted with a dash-pot of such a nature that no alteration will be made in the engine cut-off, unless the force acting on the governor is continued. Obviously

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the worst dash-pot to use is an air dash-pot; and the best a modified form of grease dash-pot; on the other hand, if very thick grease is used, in order to prevent the governor taking notice of short, sudden speed variations, the governor may be rendered so very sluggish that it becomes insensitive to speed variations of a permanent nature, causing objectionable variations in the frequency. It would certainly appear that something more than an ordinary dash-pot is required, and that these necessary fittings for the governors of large slow-speed engines might be profitably designed in accordance with the requirements for perfect parallel running of the generators. It is a point that does not appear to be as well recognised as it should be.

The fitting of special dash-pots to the engine governors reduces the swings of the generator magnet wheels to zero, or practically so, by preventing the admission of steam by the expansion valves during the periods of swing. It might happen, however, that the remedy in a particular case could not be applied for special reasons, and in this case the only remaining way of decreasing the amplitude of the oscillations would be to use damping-coils between the field-poles of the generators. The oscillations causing the phase differences between the E.M.F. waves of the various machines are accompanied by field distortion, just as described in connection with the substation machinery, and consequently they can be damped out in their early stages by the same means. On very large slow-speed generating sets it is quite certain that it will pay to use such damping coils on the generators; they should be applied as shown in Fig. 6 or in a similar way.

On account of the bending of the shafts, it is of importance with machines of very large size to arrange the generators in such a manner that they are unaffected thereby. Experience with such machines shows that no matter what size the shaft is made, the arrangement of the generators outside the engines is not so good from the point of view of parallel running as that of putting the generators between the cranks, arranging the cylinders (if necessary) tandem fashion in order to allow of this being done. With a given cyclic irregularity, the two cranks should preferably be set at an angle of 180 degrees to one another.

With regard to the governing of the engines driving the power-station generators, in order to be able to distribute the load properly, this should not be too close. It is in general quite sufficient if the speed does not rise more than 2 per cent when the load is decreased suddenly from full-load to half-load, or from half-load to no-load, and *vice-versâ*. Of course, this change of speed must not be accompanied by the slightest hunting or irregularity, and the governors must control the engines perfectly when the latter are running at no-load with stop-valves full open.

The question of the permissible speed variation in one revolution or "cyclic irregularity" is an important one, for to a certain extent it determines the amount of metal that must be put in the rim of the generator magnet wheels. The whole question turns upon the frequency employed—at a given speed a far better engine is required for high-frequency generators than for those of low-frequency, as is well known now. With a given type and speed of engine, the lower the frequency the better the parallel running, because a low frequency implies a smaller number of field-poles, and consequently the speed variation in the revolution causes a smaller phase displacement between the E.M.F. waves of the different machines in parallel, meaning smaller synchronising currents and greater stability of running.

The amount of "cyclic irregularity" permissible depends, then, upon the permissible phase displacement, and this depends, to a certain extent, upon the nature of the work. Thus for feeding rotary converters, which may be considered as being the most unfavourable case in practice, the phase displacement at any load should not exceed 2 degrees; that is to say, a point on the rotating magnet wheel may not differ more than $\frac{2}{p}$ from the position it would have if the rotation was perfectly uniform, "p" being the number of pole pairs. Thus consider the case of a standard power generator of 2,000 kilowatts at 25 cycles and 83 revolutions per minute; the number of pole pairs (p) would be 18; the permissible "cyclic irregularity" must not exceed 1/9—that is to say, a point on the rotating magnet wheel of the generator must not be more than 0·11 of a degree in advance of, or behind, the point corresponding to absolute

uniformity at the same speed. Thus the total "cyclic irregularity" or angular variation in this case would be 0·22 degrees; had the frequency been 50 it would have been 0·11 degrees for the same phase displacement of the E.M.F. waves, necessitating a much greater flywheel effect in this case.

Of course if the generators have a larger armature reaction than is usual, the permissible phase displacement can be greater for the same synchronising current. It must always be borne in mind that with generators running in parallel one may be ahead and another behind by the amount of the maximum "cyclic irregularity," so that the amount by which the two E.M.F. waves are out of phase depends upon twice this—that is, it depends upon the total amount of variation in this case; the synchronising current will be proportional naturally to the sine of this total angle of phase displacement—in the case taken above, to sine 4 degrees.

In accordance with what has been said before, the variation in angular velocity during a revolution should be kept within the permissible limits with the minimum weight of magnet wheel; that is to say, the desired result should be attained rather by careful design of the engines than by very large flywheel effects. If this point be attended to, if the governor dash-pots are suitably designed, and if the pressure regulation of the generators is not too close, there will be no trouble from hunting either in the power station or in the distant substations.

These remarks regarding the governing, speed variation, &c., of engines for power work can be concluded with the illustrations given in Fig. 9. The "tachograms" *a*, *b*, and *c*, are as nearly as possible exact reproductions of the records obtained by means of a Horn tachograph from one of the 1000-H.P. engines referred to on page 742. The variations in the angular velocity during the revolution are quite clear—the three records represent three different adjustments of the engine governor after the engine and generator had been erected. It will be seen that after the governor had been properly adjusted, the total variation (up and down) in the speed does not exceed 0·3 of 1 per cent., or the "cyclic irregularity" of the engine does not exceed 0·15 of 1 per cent. up or down. The Horn

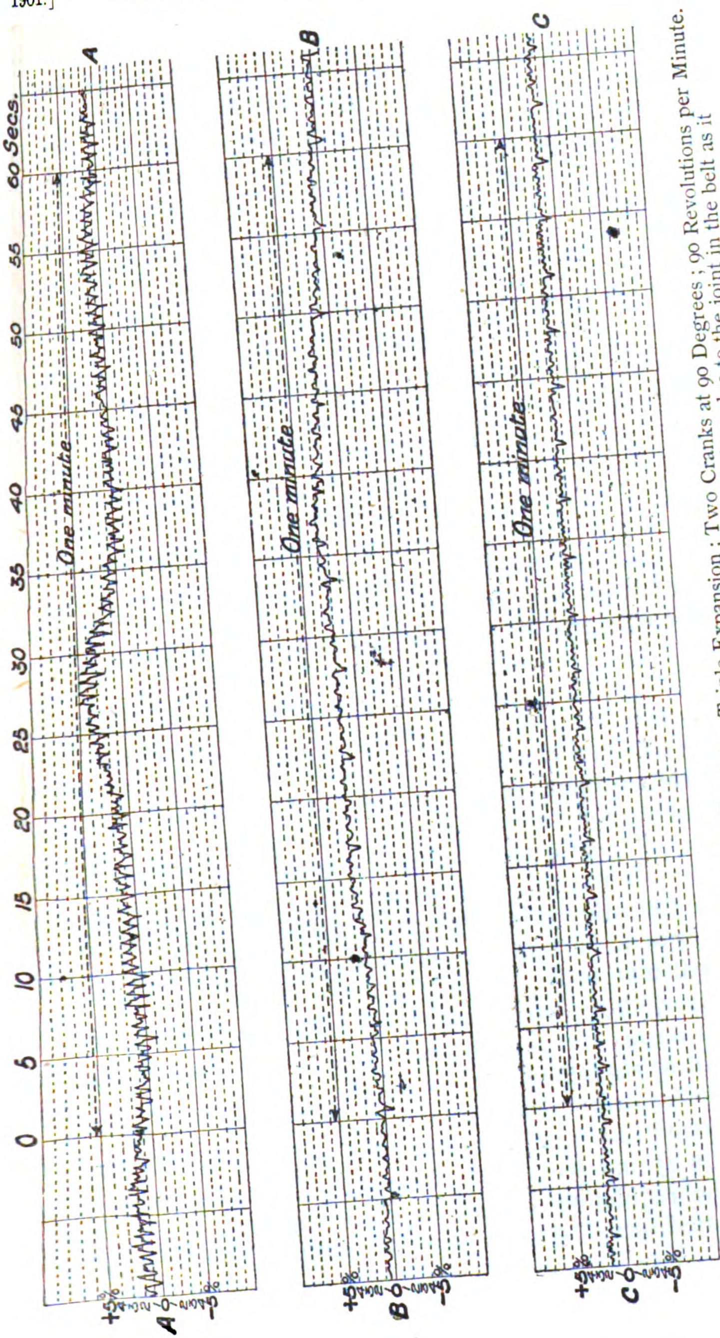

FIG. 9.—Tachograms of 1,000 B.H.P. Horizontal Engine. Triple Expansion; Two Cranks at 90 Degrees; 90 Revolutions per Minute. (NOTE.—The small depressions occurring at regular intervals in record "C" are due to the joint in the belt as it passes over the pulley of the telegraph.)

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Of course if the generators have a larger armature reaction than is usual, the permissible phase displacement can be greater for the same synchronising current. It must always be borne in mind that with generators running in parallel one may be ahead and another behind by the amount of the maximum "cyclic irregularity," so that the amount by which the two E.M.F. waves are out of phase depends upon twice this—that is, it depends upon the total amount of variation in this case; the synchronising current will be proportional naturally to the sine of this total angle of phase displacement—in the case taken above, to sine 4 degrees.

In accordance with what has been said before, the variation in angular velocity during a revolution should be kept within the permissible limits with the minimum weight of magnet wheel; that is to say, the desired result should be attained rather by careful design of the engines than by very large flywheel effects. If this point be attended to, if the governor dash-pots are suitably designed, and if the pressure regulation of the generators is not too close, there will be no trouble from hunting either in the power station or in the distant substations.

These remarks regarding the governing, speed variation, &c., of engines for power work can be concluded with the illustrations given in Fig. 9. The "tachograms" *a*, *b*, and *c*, are as nearly as possible exact reproductions of the records obtained by means of a Horn tachograph from one of the 1000-H.P. engines referred to on page 742. The variations in the angular velocity during the revolution are quite clear—the three records represent three different adjustments of the engine governor after the engine and generator had been erected. It will be seen that after the governor had been properly adjusted, the total variation (up and down) in the speed does not exceed 0·3 of 1 per cent., or the "cyclic irregularity" of the engine does not exceed 0·15 of 1 per cent. up or down. The Horn

FIG. 9.—Tachograms of 1,000 B.H.P. Horizontal Engine. Triple Expansion; Two Cranks at 90 Degrees; 90 Revolutions per Minute. (NOTE.—The small depressions occurring at regular intervals in record "C" are due to the joint in the belt as it passes over the pulley of the telegraph.)

tachograph does not appear to be so well known in this country, as it should be. It is an extremely useful instrument, whose indications represent with sufficient accuracy what the engine is doing during the revolution. This is exactly what the electrical engineer wants to know in connection with the commercial problems of parallel running.

III.—Relative Comparison of the Different Types of Substation Converters.

From what has already been said about the three classes of substation equipment, a good general idea can be formed of their relative advantages and disadvantages. From the point of view of simplicity and ease of operation asynchronous converters are far ahead of the two types of synchronous machines. But this advantage is gained at the expense of plant efficiency, and consequently, simply on account of the lagging currents incidental to their use, this type of converter is unsuitable for work of any magnitude. It will continue to find its chief use in connection with schemes for the conversion of power for lighting and tramways, where the total amount of power to be transmitted and distributed is relatively small, and where the substation converters do not exceed 150 kilowatts in size.

Synchronous motor generators, on the other hand, are ideal machines for the work in many respects. High power-factors over the whole of the system are assured; there are no complications in working, and no parallel-running troubles need be feared, provided a fair amount of care has been taken with the design of the plant in the first instance. Moreover, these machines possess (in common with the asynchronous converters) two very great advantages, the first being that they can be operated equally well from circuits of any reasonable frequency, there being no difference in the performance of the motors for frequencies between 25 and 60 cycles. The second great advantage is that the regulation of the direct-current pressure can be performed in well-known ways with the greatest ease, and not only this, but the direct-current pressure is independent of the pressure fluctuations at the ends of the long, high-pressure feeders.

Both asynchronous and synchronous motor generators are efficient types, the efficiency of the asynchronous motor being generally about 1 per cent. less than the synchronous machine, while the efficiency of the latter will be about the same as that of the direct-current generator of equal size driven by it. Both classes of machine require simple switch gear, and very little of it, the advantage being with the asynchronous machine, on account of the simple starting arrangements.

Rotary converters are on the same footing with regard to starting and power-factor as synchronous motor generators, and have two great advantages over either form of motor generator—they are 4 to 5 per cent. more efficient at all loads, and possess a greater overload capacity. They are, on the other hand, extremely sensitive with regard to parallel running; with regard to fluctuations in the feeder pressure, moreover, their manner of operation is by no means simple, and the arrangements for regulating and running are in general somewhat complicated; this is on account of the special regulating arrangements and extra switch gear required for the step-down transformers and auxiliary devices.

With regard to the important points of floor space required, and first cost, there is very little to choose between the different types of machines. Comparing the machines alone, there is of course a considerable advantage in favour of the rotary converter, but the additions to the latter equipment in the shape of transformers, air-blast outfits (when used), special regulators, and extra switch gear, bring up the cost of a rotary converter equipment to very nearly the same figure as that for the synchronous motor generator equipment; the asynchronous converter equipment is somewhat dearer than the latter as a rule.

The table given on the following page serves to illustrate the above-mentioned points in a practical way. Examples given are taken from practice, and the machines (built in the same works) are compared upon *exactly* the same basis with regard to conditions of operation, such as speed, frequency, voltage, &c. The case selected to illustrate what has been said is an actual combined lighting and power scheme, current for lighting purposes being taken from the high-pressure feeders *en route* to the substations, as well as from

the latter—hence the frequency. The case is somewhat unfavourable to the motor generators, as these machines were arranged with a generator at each end of the motor shaft, having half its output; consequently the floor space required is greater, and the cost more, than would have been the case had each motor driven a single generator of equal output.

It will be seen that with the larger machines the only substantial advantages of the rotary converter compared with the synchronous motor generator are those of greater efficiency and overload capacity. These are, of course, of very great importance, but for many purposes the greatly superior performance of the synchronous motor generator from the points of view of simplicity, parallel running, and pressure regulation must be carefully balanced against them.

Before concluding a word or two must be said with regard to the performance of rotary converters of large size at different frequencies. It is not too much to say that the limit of successful operation of these machines is reached at 40 cycles; above this frequency there is no doubt whatever in the author's mind that in all cases the best type of converter to employ in the substations is the synchronous motor generator, whatever the nature of the work. Above the frequency of 40 cycles there are two great difficulties in the way of successful working—good parallel running of the rotaries becomes extremely difficult, the machines hunting at the slightest provocation, and the question of commutation becomes a very difficult one to solve in a satisfactory manner. As already pointed out in connection with the generators, the lower the frequency the better the parallel running, for with a given angular displacement the phase difference between the E.M.F. waves of the various machines is smaller. The same argument applies equally to the case of the rotary converter, for in order to put the high-frequency machine on the same basis as the low-frequency machine in this respect, it would be necessary to have the same number of poles in each machine, meaning that a machine operating at 50 cycles would have to run at double the speed of a machine of the same output operated at 25 cycles. This is of course impossible, on account of mechanical considerations, the principle difficulty being the commutator. If on the one hand the peripheral speed of the commutator

COMPARISON OF SUBSTATION MACHINERY.

Transmission: 3-phase at 5,500 volts between lines and 40 cycles.

Distribution: 3-wire at 510 volts between outers, neutral conductor earthed.

Type of Equipment.	Asynchronous Motor generator.		Synchronous Motor generator.		Rotary Converters and Step-down Transformers.	
Output of substation converter	150 kw.	500 kw.	150 kw.	500 kw.	150 kw.	500 kw.
Speed of converter...	480	300	480	300	480	300
Number of field-poles (generator) ...	6	10	6	10	10	16
Peripheral speed of commutator ...	1760	1880	1760	1880	2970	3100
Number of commutator bars	162	270	162	270	400	560
Temperature rise, any part after 24 hours at full load...	35°C	35°C	35°C	35°C	35°C	35°C
Rise of pressure when full load switched off, sub-station bus-bar pressure constant	15%	12%	14·5%	11·5%	9·5%	8%
Efficiency Full load	83·5%	86%	84%	87%	90%	92%
Efficiency Half „	75·5%	80%	76%	79%	85%	87·5%
Overload capacity for one hour with fixed brushes ...	25%	25%	25%	25%	50%	75%
Power-factor Full load	90%	91%	100–95% (leading)	100–96% (leading)	100–95% (leading)	100–96% (leading)
Power-factor Half „	87%	88%				
Starting current from A.C. side in terms of full load current	80% (Rotor resistance.)	50% (Rotor resistance.)	100% (Starting motor.)	100% (Starting motor.)	80% (Starting motor.)	60% (Starting motor.)
Full load drop of speed	3·5%	3%	None	None	None	None
Relative cost per kilowatt, including regulating gear ...	20	15·6	19·1	13·2	12·4 (Including middle wire booster.)	13·0 (Including middle wire booster.)
Floor space required per kilowatt (square feet)	0·8	0·5	0·75	0·5	0·55	0·45

is too great, the use of carbon brushes is rendered very difficult, and also the segments may buckle, while on the other hand, as the number of segments required is practically fixed (by the permissible voltage per bar), these would become too thin if the diameter of the commutator is less than a certain amount. The higher the direct-current pressure, the greater the difficulties in this respect. The nett result is that with high frequency the number of field poles on the rotary has to be increased, the diameter of the armature has to be increased (which means increased momentum), and also the armature reaction of the machine has to be made larger, in order to get a proper division of the current in the various branches of the armature. All these features, common more or less to the high-frequency rotary, namely, crowded poles, high peripheral speeds, high armature reaction, thin commutator segments, high voltage per bar, short distance between brush holders, &c., are wholly unfavourable to successful parallel running and good commutation, to say nothing of the increased wear and tear due to abnormally high speed. It is for this reason that a frequency of 25 cycles has been standardised for rotary converter work, and at this frequency the machines are undoubtedly satisfactory. Between 30 and 40 cycles their performance is still good under favourable conditions (that is, proportionately better engines, high speeds and low voltages), while above 40 cycles the use of the rotary converter, in units of large size, would appear to be practically out of the question.

Low frequency of operation, such as 25 cycles, while satisfactory, if the whole output of the power-station is to be absorbed by the converter substations, is undesirable if other work has to be done in addition. Generators, motors, and transformers become unduly heavy and expensive, and lighting work from the alternating current mains is out of the question. But, on the other hand, all parallel running is better, and all inductive effects in generator, line, transformers, and motors, diminish with low frequency, resulting in improved regulation over the whole system. Taking all these things into account, modern practice has shown that a frequency of 40–50 cycles is the best that can be employed for the work in question ; a departure from this in order to suit the requirements of the rotary

converters in the substations constitutes in itself a disadvantage which is not present when motor generators are used for the same work.

Concluding Remarks.

Given that it is required to convert polyphase current into direct current by means of converting substations, it is possible, based upon the considerations noted in the paper, to draw the following general conclusions :—

1. For power work, and for those cases where the amount of lighting to be done is relatively small, rotary converter substations operated at 20–30 cycles are preferable.

2. For lighting work, the use of motor generators, operated at 40–50 cycles in the substations, will give the best results. This is also the case when the lighting load on the substation forms a considerable proportion of the total output of the latter.

3. Of the two classes of motor generator substation that equipped with asynchronous machinery is on the whole unsuitable for work of any magnitude.

The above conclusions may perhaps form a basis for discussion, but they must not be considered as being perfectly definite, on account of the widely different conditions that are met with in modern practice. Finally, the author would like to suggest in this connection that the discussion might profitably include the broad question of the transformation and distribution of large amounts of polyphase current for supply over large areas, for it is one of the most important questions of modern electrical engineering. Although in many cases direct-current substations are undoubtedly advisable, still in many cases the direct distribution of polyphase current from simple transformer substations will undoubtedly be the best solution, not only from the technical, but also from the commercial point of view.

Mr. M. B. Field: I did not come here to-night with the intention of speaking, and of course I had no idea that I should be called upon to open the discussion. Unfortunately I have only seen the paper for a few minutes, and owing to the fact that merely an abstract has been read to-night I have only a very small idea of its real Mr. Field.

Mr. Field. contents, so that under the circumstances it is quite impossible for me to discuss it adequately. It seems to me, however, to be a paper containing a large amount of useful information, and to contain a number of points which might very profitably be discussed at length.

I think American engineers, after a large amount of experience, have come to the conclusion that the correct substation converter to use is the rotary, *provided the frequency be low*. With rotary converters 25 cycles give the best results; the full-load efficiency may be taken at 95 per cent. or 93 per cent. with transformers. This is certainly higher than that of any other type of converter. A good rotary may be started up with not more than 30 per cent. above full-load current, and will stand 2½ times full load without the least instability.

With frequencies above 30 it begins to be questionable as to whether motor generators are not on the whole as favourable as rotaries; after 50 cycles rotaries are likely to give trouble, though the Westinghouse Company do not hesitate to build them up to 60 cycles.

The Metropolitan Railway Company in New York transform, I believe, some 60,000 H.P. by means of rotaries without the least difficulty; in Glasgow some twenty-four rotaries of 500 kw. each have already been put down.

In the latter case each rotary is direct connected to a booster of 30 kw. to be connected to the rail return cables; the rotaries are compound-wound and have no independent regulating devices other than the field rheostats in the shunt circuits. The transformers are specially designed to have a large self-induction; in fact, they would show a 12 per cent. drop on full-load inductive current. The effect of this self-induction is to raise or lower the terminal E.M.F. in the secondary according as the current is a leading or lagging one, this being determined by the degree of excitation of the rotary. Thus by varying the excitation of the rotary the ratio of transformation of the transformers is virtually varied and adjusted.

Mr. Eborall laid considerable stress on placing the damping copper bridges between the poles, and he states, I believe, that it is useless to place them round the poles.

Here I disagree with Mr. Eborall. Many makers adopt heavy copper rings round the poles, using them to hold the pole windings in place. These rings are thickened up materially at the pole horns and often envelope the latter. Now if the pole flux be not abnormally distorted the whole flux will pass through the ring, and before it can be blown outside it must cut across the ring. The currents thereby called into being react upon the field and prevent it becoming distorted to any extent. Moreover, by enveloping the pole tips with the copper rings, rapid variations of flux at these parts are prevented.

The question of substation converters for higher frequencies, say 50 cycles, is an interesting one, and I think a workable combination would be pairs, each consisting of one powerful synchronous and one non-synchronous motor generator—the former to be over-excited and thus compensate for the lagging current of the latter. This would give a substation very easy to start up, stable as regards running and overloads, and giving a power-factor of approximately unity.

Mr. Field.

It occasionally occurs that a rotary is required to be run the reverse way. This is somewhat a dangerous proceeding, unless adequate precautions be adopted, for if the current taken from the slip-rings be a lagging one, the field becomes demagnetised and the rotary speeds up perhaps to a dangerous degree. In any case the variation of frequency is objectionable.

In Dublin a rotary is often run in this way reversed (*i.e.*, fed with continuous current), and the method adopted to overcome the difficulty mentioned above is interesting.

Connected to the main rotary, which is compound-wound, is an auxiliary rotary with the same number of poles, and fed with three-phase currents by means of three-series transformers placed in the main three-phase line. The commutator of the auxiliary merely supplies the compounding current for the main rotary. The auxiliary has no field winding, the magnetism being supplied by the current in its armature.

If, now, when the line current is in phase with the supply E.M.F. the auxiliary field system be turned into such a position that it does not become magnetised by the armature currents of the auxiliary rotary, when the main current is lagging the auxiliary field system will be magnetised in the one direction, and when leading the auxiliary field system will be magnetised in the reverse sense. Under these circumstances a corresponding compounding or decompounding current will flow from the auxiliary brushes round the field magnets of the main rotary. In Dublin the speed variation with this arrangement is never more than two or three revolutions. The auxiliary rotary will have an output of, say, ½ to 1 per cent. of the main rotary; that is to say, it is quite a small affair.

On page 716 Mr. Eborall gives me credit for a particular form of regulator. I believe this is quite an old idea, and has been in vogue in America for years. I believe I hit upon it independently, but do not take credit to myself for originality in this respect.

Dr. Thompson.

Dr. SILVANUS THOMPSON: The author on page 710 speaks of certain advantages of the mesh-connection for three-phase work over the star-connection. Some of these advantages were certainly known before, but I do not remember their ever having been previously stated in any published paper. Therefore whether they were known before or not, our thanks are certainly due to him for stating them now.

With respect to the use of damping coils between the pole faces which is mentioned on page 736, I was about to draw attention to this point, but Mr. Field has already to some extent dealt with it. While I agree with Mr. Field that there is some advantage in putting a thick copper coil around the pole, I do not stop there, because that arrangement certainly does not ensure the whole advantage. You may have a reaction due to lagging or leading current, which tends decidedly to demagnetise the poles by distorting the magnetism to one side and producing an unequal distribution over the face, quite independently of any production, by an auxiliary distortion, of a magnetic field in the space between the poles. I think that I am not wrong in saying that the distortion actually over the pole surface itself, within the area of an enclosing coil, might be quite sufficient to admit of the

Dr. Thompson

instability known as hunting. Therefore the remedy is not necessarily either to put the ring of copper round the pole face, or to put copper damping coils between the pole faces. The real and complete remedy is, I believe, the original one, viz., that which I emphasised in my address here a year and a half ago—the use of an amortisseur on the plan of Leblanc, which consists in putting a number of closed copper circuits, like a squirrel-cage, embedded in the pole face, so that there are circuits through the pole faces, as well as round them and between them. That this is of some use is obvious from the way in which amortisseurs are gradually coming into practice. Take for example the largest of all the three-phase machines exhibited in the Paris Exhibition last autumn. I mean the very large three-thousand kilowatt machine which was exhibited by the Allgemeine Company of Berlin, and of which several were built for the purpose of their large new station at Ober Schönweide. These machines had the pole faces pierced with five holes from front to back—five holes of different sizes, with five copper rods inserted, one through each hole. The ends of those copper rods united together, making practically a squirrel-cage embedded in the pole. I fancy this would be found far more effectual than merely putting copper wedges between the poles, or copper rings around the pole faces.

Another matter mentioned by Mr. Eborall on pages 739 and 740 is that of the use of three-phase choking coils. He mentions as a point of some interest that among the disturbing effects of the capacity of lines is this tendency to accentuate any hunting in the machine. The use of choking coils placed across the machine circuit, for the purpose of obviating this, is distinctly interesting. I know that Mr. Mordey has been at work on this question of the idle current in the net work, and it also interests me because I happen in 1893 to have pointed out an advantage in a three-phase distribution (where there was, of course, a capacity between the three lines) of putting in three-phase choking coils distributed at regular intervals along the capacity.

Then coming down to the question of the variation of speed of engines, this is a matter that I happen to have been discussing lately with my colleague, Professor Dalby, who has touched upon it in his recent lectures on the Balancing of engines. In those lectures Professor Dalby gave some data about the amount of variation of speed for engines of different types. I do not remember to have seen anywhere published any exact data about the variations of angular speed of engines of different types under different circumstances. I should like to put to some of those who are interested in engine speeds this question, as being one on which it is most important that we should have as full information as possible: What kind of a specification for an engine can be drawn up so as to ensure that the cyclic irregularity shall not exceed the permissible minimum? and what means are there, beside the Horn Tachograph, of measuring, of indicating, or of recording, on any given engine-set, the amount of cyclic variations under different conditions?

Lastly, I want to thank Mr. Eborall for having given us such a complete statement of the case for these combined motor-generator sets.

It was my lot rather more than two years ago to read a paper here on the other solution of this problem, namely, that of the rotatory converter. Certainly Mr. Eborall has made out a good case for the employment of motor-generators under the conditions that he contemplates of supplying large quantities of electric energy by a three-phase system, at a high voltage, with substations for the purpose of converting to continuous-current. After all, does it not remain to be proved that whether you use rotatory converters, or whether you use these combined motor-generators, you will after all only make the best of what is not in itself a very perfect job? You are putting down into substations a quantity of revolving machinery which requires incessant attention; and if you can by simplifying your system get rid of all the revolving machinery in intermediate stations between the generating station and the consumer, so much the better for the system and so much the better in the long run for the engineer and for the industry. I regard all this revolving machinery in intermediate stations as a kind of temporising with that which after all is not a perfect or satisfactory solution of the problem. I look forward to the time when we shall do without it. There are many ways of doing it, of course; but one way is certainly first to simplify matters, not using continuous-currents at all, but doing everything while you are about it by the three-phase current. I know it is an old question and a sore question. It is a question which we have discussed here, and a question which our Manchester friends have discussed in their own way. They have come to a somewhat surprising conclusion—or, perhaps, a conclusion not surprising at all, if they have got such extraordinary ideas as to suppose that continuous-current motors are either lighter, more regular in speed, more efficient, or more cheaply made than three-phase machines. If they put their heads in the sand and choose to start an argument by the assumption that these things are so, then of course they will come to the conclusion that it is better to work with continuous-currents. But if their premises are unsound, the arguments are absolutely baseless. That is not, however, the question now before us, save in so far as it affects the question whether the disadvantages involved in transforming from three-phase to continuous-currents do not afford a strong additional reason why the three-phase system in all its simplicity should be preserved. Why throw away its advantages for the sake of being able to use a kind of motor that is heavier, dearer to build, less regular in speed, and which has the additional disadvantage of having a commutator that requires attention? Dr. Thompson.

Mr. S. Z. DE FERRANTI: I think this paper has done a great deal of good in emphasising the extreme complication of the system which is required to convert every alternating-current into a continuous. Briefly, it leads one to think that the only excuse for employing a continuous-current instead of using an alternating-current direct in one form or another, is to be found in the case where two companies are in competition and where they have to deal with a public feeling that continuous-current is much better for the consumer than alternating-current, and so have to give it to him, in order to be able to sell at a price in competition with the other company. That, to my mind, is the Mr. Ferranti

Mr. Ferranti.

real reason of the existence of so much continuous-current in a great city like London. This paper shows how very ingenious people can be and what beautiful inventions can be brought out to fit almost every possible condition that the working out of the secrets of nature can involve. But I think myself that the highest form of cleverness, and also the most permanent good, are got from the simplest possible appliances and systems generally. I do think with Dr. Thompson that all that is shown here is very largely a makeshift in order to adapt high-tension alternating generation and transmission to the necessity of our present demand. I do not think it is going to be permanent, and yet it has already evolved the greatest possible skill in meeting the particular case. I think that before long the principal cause of the persistence of systems of this class, namely, electric locomotion with a continuous-current, will be supplanted by alternating-current locomotives for motor cars, or whatever it may be, running on rails. That is the principal demand at present for such a system as we have heard discussed here—the competition between various companies supplying alternating- and continuous-current. I am not prepared to give any opinion about it. My experience in London is that it is a matter of the canvassers who are engaged, much more than the actual value of the stuff supplied. With regard to the technical part of the paper, I do not wish that any of my remarks should be taken in any way to belittle the very interesting paper which has been given to us to-night, or Mr. Field's remarks upon it, which were most interesting. With regard to the detail of this subject, the hunting of these converters or motor-generators, I certainly agree with Dr. Thompson that the true solution is the original one invented by Le Blanc, which went into the thing very fully. He is a most profound mathematician, and I think that those who know the results that he has obtained will feel satisfied that his mathematics agree very well with practice.

Mr. Esson.

Mr. W. B. ESSON: Unfortunately, like some of the previous speakers, I have only been able to glance at the paper, but I see that it requires a considerable amount of attention and study, and without, one is unable to appreciate its full value or discuss it properly. I have only had experience of one of the types of substation referred to by Mr. Eborall. That is the first, in which are used induction motors with direct-current generators coupled one at each end, forming a three-wire system. The case to which I refer was not a simple case of transmission from a distance, but a case in which we had to distribute the energy through a mixed area, alternating-current being supplied in one part and continuous-current in another part, a condition insisted on by the Board of Trade in terms of the idea of competition which has been referred to by Mr. Ferranti. We fully considered at the time the best way of carrying these conditions out. We had first of all to generate an alternating two-phase current at 3,000 volts, and the question then had to be settled as to the best way of converting this into a continuous-current. We fully discussed the three different methods mentioned by Mr. Eborall—the synchronous motor, the induction motor, and the rotary converter. Rotary converters for some reason or another do not find favour with engineers in this

country. I have had no experience of their working myself, and judging from the experience of some of my friends who have, I am not particularly sorry. In our case they were not adopted. The induction motor was found to give by far the most simple arrangement, as Mr. Eborall says, for starting and management, and so it was used. There is one point that we kept in mind which I do not think has been referred to by Mr. Eborall. Supposing that for some reason or another a temporary short occurs in the distributors. The induction motor being now overloaded, slows down, but on the short being removed or burning itself out, it at once picks its speed up again, whereas with a synchronous motor you would have considerable difficulty as regards starting in the event of such a case arising. Mr. Esson.

There is one point which must not be overlooked when working motors in this way. The regulation must be very fine. If you are working induction motors in sub-stations, the ordinary resistance for the rotor which admits of the machine starting with a current equal to the full load current is of no use. The resistance must be very much higher so that quite a fractional current is allowed to flow at the start. Otherwise you get fluctuations on the alternating-current portions of the system and upset your customers. I should think that for a sub-station the usual starting resistances would be quite impossible.

Coming to details, I think Mr. Eborall in one part of his paper mentions an air-gap of a tenth of an inch in an induction motor having a 3 feet 9 inch diameter rotor. Well, that is very small indeed. I think that it is really too small for safety. The American practice is to give a much larger air-gap than that, and the usual Continental practice would be to give for a motor of that size quite 50 per cent. more than Mr. Eborall mentions.

In his paper Mr. Eborall gives some pictures of machines, which, however, are not described particularly. I refer to the machines supplied to the Metropolitan Company. The striking thing about Continental machines is that they seem to be so much lighter in weight than the English. They appear to have far less material in them, and I should like to ask Mr. Eborall what would be the drop in the synchronous motor referred to. We are now making machines in this country with a drop from no load to full load of two and a half or three per cent.; but it would certainly appear that this machine has a drop of something like six or eight per cent. Of course it is impossible, if we put so much more material into our machines, to compete in price with Continental work, and the fact is that the English engineers are making machines too good. They will have to diminish the size and increase the drop to compete with makers on the other side. There is no royal road, of course, to diminishing the drop in an alternator. There are only two methods, increasing the strength of the field or diminishing the turns on the armature. I know that the field strength is in Continental machines pretty much the same as we have it here—about 7,000 c.g.s. units. Therefore there must be more turns in the armature, and consequently a larger drop.

Referring to the matter of hunting, I have had a good deal of trouble

Mr. Esson. with this in horizontal engines worked by the usual Corliss trip gear, and the trouble was found to be simply due to the fact that the trip cams were not of the proper shape. There is a certain difference of speed for no load and full load corresponding to the different positions of the governor. For each intermediate speed there is a perfectly definite position of the governor and a certain cut-off which will accord with the particular load corresponding to that speed. The great thing is to shape the cams or tappets so that for every position of the governor they give the exact cut-off corresponding to the load for the particular speed, and unless they are so shaped hunting results. I should like to thank Mr. Eborall for the very interesting paper that he has given to us. It certainly deserves the most careful study, and its appearance is very opportune at the present moment.

Prof. Carus-Wilson. Professor C. A. CARUS-WILSON: I should like to draw attention to the question of the momentum of rotary convertrs, more particularly to the case of those used for traction work in which the primary circuit is well regulated, the irregularities being due to large variations of load on the secondary side. Mr. Eborall states that "the momentum of the converters should be kept as low as possible, for this apparently indirectly assists hunting." As a matter of fact, the momentum is the cause of the cross flux, and is therefore of more importance than appears in the paper. When a heavy load is drawn from the secondary side of a rotary there is a large disproportion of mechanical torque between the two sides of the rotary, giving rise to a large cross flux. The same thing can be seen if a brake is put on a rotary while it is running and mechanical power taken off the shaft; the immediate effect is to produce a cross flux. A rotary working without any frictional or torque losses on its own shaft has the torque on the two sides balanced and has no cross flux. Cross flux is the inevitable accompaniment of torque on the shaft, that is, a disproportion of torque between the primary and the secondary sides. When a sudden load is thrown on the secondary side, as in traction work, a disproportion of torque between the two sides is caused by the momentum of the armature, which will not allow the primary torque to follow up the sudden demand on the secondary side, and this gives rise to a cross flux. The greater the momentum of the armature the greater is the disproportion of torque between the two sides, and the greater the amount of cross flux. It is therefore correct to say that it is entirely due to the momentum of the rotating parts that this inequality of torque is set up and the cross flux thereby produced. But I venture to disagree with Mr. Eborall in his conclusion that on that account one should reduce the momentum of the rotary as low as possible, because while the momentum is the cause of the cross flux it reduces the extent of the oscillation caused by a sudden overload. There are twol other things beside the mechanical momentum of the armature which influence the cross flux. One of these is the resistance of the rotary; the greater the resistance the greater will be the disproportion of torque, and therefore the greater the cross flux. The other is the strength of the magnetic field; the stronger the field the less will be the disproportion of a torque between the two sides; that is to say that

a strong field counterbalances the effect of large momentum; the influence of the field is proportional to the square of the strength of the field. That is borne out by Mr. Eborall when he says that with an under-excited field the flux is more readily distorted. I cannot agree, however, with his explanation of this fact. It is not because the field is "stiff," but because a strong field has an opposite effect to mechanical momentum, and the stronger the field the less will be the effect of the momentum, so that the cross flux caused by a sudden overload is reduced by a small momentum or a strong field. Some time ago a good deal was said about having subsidiary motor-generators or motors stationed along the line in order to give relief to the line when a very sudden overload was taken and to prevent a drop in the feeders, the motors acting as generators when the pressure was lowered. We have in the rotary converter just this very thing. The energy stored as momentum in a rotary converter acts as a buffer in preventing sudden overloads in the secondary being reproduced in the primary. Following out this idea, it appears desirable to adopt that type of machinery in substations which will admit of the greatest amount of momentum being placed in the rotating parts of the converter or motor-generator. Prof. Carus-Wilson.

Mr. E. G. CRUISE: My contribution to the discussion will be a very small one. In fact, it is more in the nature of a question. However, before I ask a question there is just one other point in connection with the paper. Mr. Eborall does not touch at all upon the question of polyphase transformers as against three single-phase transformers. At least he does not touch upon it much in connection with the paper. But these kind of transformers are being very much used abroad, and it is a question whether they cannot be used in this country. As far as I can see, such type of transformers will be considerably more economical, take up less floor space, and altogether will be cheaper. There is a certain fear in this country, because if one of the phases breaks down the whole transformer is put *hors de combat.* But I think you might carry back the same argument to a certain extent to a three-phase generator: if one of the phases is broken down, the generator is also put *hors de combat;* but one would not think of replacing the three-phase generator with three single-phase generators for that reason. I think that it is largely a question of manufacture and of giving attention to it in manufacture. I do not think that it has been thought out at all in this country. They go into these details very much more on the Continent than we do, and they have made it a practical success there. Mr. Cruise.

The other point in connection with the paper is that on page 714 Mr. Eborall says that there would be no difficulty whatsoever in the regulation of synchronous motor-generators. But I should like to ask Mr. Eborall whether that assumes that the line pressure is absolutely constant; because as far as I can see in these power schemes, one of the difficulties would be to keep the line pressure constant, when you are feeding, say, half a dozen substations over a considerable length from one trunk line. I do not see that it would be financially possible to take a separate feeder to each substation. Of course if you do that, there can be no difficulty in regulating the pressure at the substation

Mr. Cruise. end. I should like to ask Mr. Eborall, as I say, how far he thinks the pressure may vary not to interfere with the working of the synchronous motor, because theoretically—I do not know how far it applies in practice, but theoretically—the output of the motor ought to vary in the relation of the square of the impressed volts, so that if you vary the impressed volts very much you have a very difficult state of affairs to deal with quite apart from the regulation on the low-tension side.

Mr. Patchell. Mr. W. H. PATCHELL: I wish we could have heard Professor Salomon on this very interesting paper, and also I would rather that you had called on some of the members in the room who have had experience with the running of this class of machinery. Up to the present I have not had such experience, but I am one of those who would have been very glad to have had Mr. Eborall's paper in their hands earlier. I had to look round to see what could be done, and then had the courage of my convictions. You may have a notion from the discussion to-night of what I suffered when I sent out my plant inquiry. I had men coming round and saying, "You must have three-phase." Another said, "You must have one-phase"; another said, "You must have nothing but rotaries." Another said, "You must use statics"; another said, "Do not use statics." It reminds me of an anecdote that the late Mr. Willans told in this room some fourteen years ago. A doctor was called in to see a woman's child. He did not know what was the matter with it, but he said, "I will give it a dose that will give it fits, and I know how to cure fits." It may interest the meeting to know what types I settled upon. I first decided that we must do without statics, as I quite agree with Professor Thompson that we must have no more plant than is absolutely necessary on the premises. My generating plant units are large enough to get ten thousand volts directly on them without sacrificing either efficiency or prime cost.

When we come to the substations it is another matter. You have to consider what class of work is to be done. If you are doing tram work or can supply from very large units in your substations it is a very different matter to supplying for lighting in our area. We have to supply from somewhat small units, because, due to our varying loads in different districts, we have a lot of different pressures. I looked round for the smallest size of motor I could get wound for 10,000 volts. I found 300 kilowatts; so about that size, 300 kilowatts at the motor-generator, was what I asked for. Then as between induction-motors and synchronous motors we require small machines for balancing, so I decided on one induction-motor driving two 150-kilowatt direct-current generators for the single-pressure machines, and a synchronous motor driving one 300-kilowatt direct-current generator for the double-pressure machines. Thus we get the benefit of induction-motors which start rapidly, and also synchronous motors which give a good power-factor, and which are arranged to start from the direct-current side.

It may interest the members, as they are visiting Frankfort in July, to know that our plant will be ready for delivery at that time; so I hope that they will have the benefit of seeing it when they go to Messrs. Lahmeyer's works.

I very much hoped that Professor Salomon would be able to speak

on the paper to-night, but perhaps the President will ask him to give us a contribution in writing. Mr. Patchell.

Mr. C. P. SPARKS: I think we Engineers here in England are in agreement with the writer of this paper so far as his conclusion No. 2, namely, that for general purposes the simplicity derived from the use of motor-generators is more desirable than the extra efficiency offered by use of rotaries. Mr. Sparks.

There is one point to which I should like to draw attention, the question of distribution from the high-pressure substation. If one has a scattered area, with factories here and there, the polyphase system can be continued so as to supply both light and power from the same mains. But when we come to a question of low-tension networks there is little advantage in using polyphase current, more especially in populous districts, owing to the greater expense in laying a polyphase network compared with a three-wire direct-current network. The only reason in favour of the polyphase C.C. networks is difficulty through electrolysis, and this has been largely met by the introduction of triple concentric cables with the neutral conductor placed on the outside, connected to "Earth."

Another point in favour of the continuous-current network is that, at the moment, although polyphase motors are lighter, and we are told less expensive to manufacture, no polyphase motor of the usual working sizes can to-day be bought for the same price as a direct-current motor. This circumstance, coupled with delay in obtaining delivery, severely handicaps any company supplying polyphase energy in competition with direct-current supply, as no argument can outweigh the fact of first cost to the consumer.

Mr. H. L. LEACH (*communicated*): The author's paper is extremely welcome to many electrical engineers in this country who have had little or no practical experience, up to the present time, of three-phase construction or working; and the paper will be appreciated by all who wish to study the advantages and disadvantages of three-phase transmission and distribution of electric energy. Mr. Leach.

The curves of "cyclic irregularity" in Fig. 9, obtained by means of the Horn Tachograph, are very interesting and instructive. As this instrument is probably unknown to many engineers in this country, it would be advantageous if the author could inform us where it can be obtained; it would prove of immense value to our engine-builders and central-station engineers.

Mention was made, in the author's reply to the discussion, of several lighting stations on the Continent where the three-phase system is now in use for both the generation and distribution of three-phase currents to the consumers' houses. It would, I think, be of great interest to members of this Institution, if Mr. Eborall could supplement his paper with a list of some of such central stations, together with particulars of the H.P., or output, periodicity, pressure of the high-tension transmission lines and voltage of the supply-mains to the consumers.

Mr. H. J. EDWARDS (*communicated*): Since the meeting at which Mr. Eborall's paper was read, it has occurred to me that the experience gained at the Power-house of the Cleveland Electric Illuminating Mr. Edwards.

Mr. Edwards. Company, Cleveland, Ohio, might be of some interest to you. They have several rotaries there for charging their large batteries, and at first were troubled very much with the hunting spoken of by several members the other evening. At first they tried the copper bridges suggested by Mr. Steinmetz, but on account of the enormous heating of the bridges they displaced the copper ones for similar bridges made of aluminium, but without any very satisfactory results, and indeed they never effectually got rid of the hunting until they put dash pots on the governors of the engines, since when they have had no trouble whatever. I quite agreed with remarks made by Dr. Thompson and others with regard to the idea of doing away with all such troublesome accessories as rotaries, etc., but in view of the perfection of the Electric Motor Carriage and the coming demand for the same, there must be some way of establishing charging stations, either public or private. With this in view, the Automobile Department of the Cleveland Screw Company, with whom I am now connected, have very satisfactorily developed a small rectifier for this purpose.

Mr. Leake. Mr. H. C. LEAKE (*communicated*): Mr. Eborall's remarks on the subject of parallel running are of the greatest interest, as this is one of the most important points in connection with the operation of large systems.

It is quite new to me that the parallel running of well-designed generating sets is affected by the relative position of engine and alternator, and I think further explanation of this point would be of general interest.

In the same paragraph Mr. Eborall recommends that the engine cranks should be 180 degrees apart, but this appears to be inconsistent with a paragraph which follows later, in which he says that the variation in angular velocity during a revolution should be kept within the permissible limits rather by careful design of the engines than by very large flywheel effects. Would not placing the two cranks at right angles, instead of 180 degrees, usually help in this direction?

The employment of a given "cyclic irregularity" depending on the number of poles is not, in the writer's opinion, a very rational method of designing alternate-current generating sets for parallel running, although no doubt this method is very widely used; since it is probable that hunting of synchronous machinery is in many cases of the nature of a resonance effect, and the "cyclic irregularity" of a generating set on a load *offering a constant torque* bears no direct relation to the liability for such resonance to occur when it is operating in parallel with other synchronous machinery. The tachograms given in Fig. 9 are interesting, but would be more instructive if Mr. Eborall would give information as to the conditions under which they were obtained. For instance, it should be stated whether the engine was running alone or in parallel with the other one, and whether the load was synchronous or of the nature of a resistance.

Referring to Plate 3, between the motor and the generator is shown an arrangement looking like a flexible coupling. This is, I think, unusual on machinery of this kind, and it would be interesting if Mr. Eborall would explain the object of it.

Professor E. WILSON (*communicated*): Mr. Eborall refers to the commercial use of a choking coil with movable core for controlling the potential difference between the slip-rings of rotary converters. About a year ago Mr. R. D. T. Alexander constructed for me an automatic device for effecting a somewhat similar regulation. The figure shows the device as applied to a three-phase rotary converter A. In each of the three conductors leading to the slip-rings is placed a choking coil B; the three choking coils being of identical construction. The conductor leading from one brush on the commutator is carried round all three magnetic circuits of the choking coils BBB. When the turns are suitably adjusted as regards number and direction, and the converter runs unloaded, the choking coils offer considerable reaction in each of the three-phase circuits, but none in the direct-current circuit. As the load comes on, the magnetising force due to the direct-current has the effect of reducing the reaction, since the net magnetising force acting upon each magnetic circuit, although varying with the same frequency as Prof. Wilson.

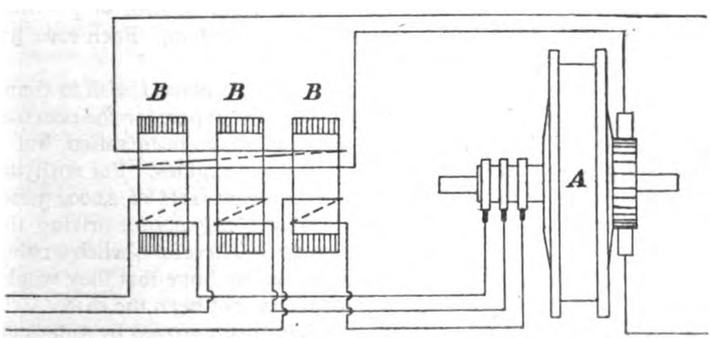

FIG. A.

the supply, has not equal positive and negative amplitudes. In fact, the axis of time may be so displaced that the net magnetising force has always the same sign. The arrangement used by me has four magnetic circuits respectively interlinked with the four conductors leading to the slip-rings of a two-phase rotary converter. The dissipation of energy in the magnetic circuits of the choking coils diminishes with increasing load on the converter.

It is in the *over-compounding* of rotary converters that the choking coil as ordinarily used is so valuable, since it can be made to increase the potential difference at the slip-rings above that of the supply circuit. If the potential difference on the side of such choking coils remote from the converter were rigidly controlled, the variation of potential difference at the slip-rings would be determined by the amplitude of the choking coil potential difference and its phase. Starting with a lagging (*i.e.*, magnetising) current at no-load, the compounding coils of the converter have to accelerate the current against an increasing potential difference at the slip-rings, due to the choking coil E.M.F. being also accelerated in phase by the current. Consequently the ampere-turns required to

Prof. Wilson. produce a given compounding effect are greater than would be required in an ordinary generator. For instance, in a two-phase rotary converter at King's College, London, run at constant speed, the potential difference was rigidly controlled on the side of the choking coils remote from the converter. On no-load the lag of current was about 70°, and when loaded the lead of current was 25°. An over-compounding effect of 17·6 per cent. on the value of the volts at no-load was observed on the commutator of the converter, when the ampere-turns due to the magnet winding were increased 59 per cent. on the no-load value. The same machine was then run as a generator at the same speed, with the same exciting currents in the magnet winding, and the same load. The over-compounding effect was 31·3 per cent. on the value of the volts observed when the generator was unloaded. When the potential difference, assumed above to be rigidly controlled, is caused to vary, as is the case in practice, it is clear that the conditions have to be carefully considered, and may bring about important alterations in design and regulation. In the design of substations generally it is of great importance to consider what may be termed the rigid control of potential difference, and if this exists at any point of the system. Each case has to be considered on its own merits.

Mr. Eborall. Mr. A. C. EBORALL, in reply, said: In the first place I wish to thank those members who have kindly discussed the paper, for the remarks they have made. Many interesting questions have been raised, but it is rather a pity we have not heard more about engines. For with the large generating units of to-day and to-morrow (sets of 2,000, 3,000, and 5,000 kilowatts), the question of suitable engines for driving the polyphase generators is a very important one. Therefore, when writing the paper, I touched on the leading points in the hope that they would provoke discussion, and am sorry that this has not been the case.

Mr. Field says that rotary converters have been proved by American engineers to be preferable to motor-generators, provided the frequency is low; I think, however, these machines have been invariably employed in the States in connection with tramway and railway work, and in that case American experience would certainly appear to be justified, and is quite in accordance with my own views. But for lighting work, where good pressure regulation is of great importance, synchronous motor-generators present distinct advantages. Moreover, as pointed out in the paper, the necessity for employing such low frequencies as 25 to 30 cycles presents several disadvantages—the generators and transformers become heavier and more expensive, whilst all lighting work directly from the polyphase mains becomes an impossibility.

The employment of rotary converters on 50 and 60 cycle circuits presents several great disadvantages, and referring to Mr. Field's statement, I think all the high-frequency rotary converters built by the Westinghouse Company must have been supplied with current from generators driven by turbines. For I cannot conceive of any worse piece of electrical engineering than to build large rotary converters of 50–60 cycles to be operated from slow-speed *steam-driven* generators; substations equipped with such machines would prove to be an incessant source of trouble and would never work satisfactorily.

Mr. Eborall.

I do not think that it is advisable to design the transformers supplying current to the rotary converters in such a way that they have great magnetic leakage (as at Glasgow) in order to get the necessary inductance in the alternating-current side of the converters. It seems to me that it is far preferable to use separate choking coils. For the employment of transformers with large magnetic leakage means that special transformers have to be built for each case, and once the transformers are built it is not possible to vary the amount of inductance; this can always be easily done when separate choking coils are used, and is frequently necessary. Moreover, from the point of view of transformer construction (apart from the question of drop) magnetic leakage may prove a great disadvantage, for with large transformers it is usual to wind the secondary with several coils in parallel, and if there is much magnetic leakage (implying that the primary and secondary coils are not sandwiched) it is easily possible to get different induced E.M.F.'s in the secondary coils in parallel, which will, therefore, not divide the load properly; those secondary coils nearest to the primary coils will do most of the work, and in consequence the heat will be concentrated at this point, causing possible damage to the insulation and risk of breakdown.

With reference to the use of damping coils on the field poles of synchronous machinery, I think I have been somewhat misunderstood; my point is that the copper is wanted principally at the pole horns, parallel to the armature, and that putting copper anywhere else would be an unnecessary expense, especially for machines with solid pole-shoes. To thread copper bars through perforated pole-shoes is somewhat expensive, and therefore such a construction is not justified unless the damping effect is considerably increased thereby. My own observations tend to show that damping coils embedded in the pole-shoes themselves are of small use compared with those properly arranged in the gap between adjacent poles, the copper being concentrated as much as possible on the pole-horns. I have been recently informed, moreover, that the standard practice of the General Electric Company (U.S.A.), who have had probably more experience than any other firm in this work, is to employ damping coils in the manner advocated by me. The Central London rotary converters, for instance, have the pole-shoes connected simply by copper strips extending from horn to horn. As the hunting of synchronous machinery is always accompanied by a swinging of the field flux from the pole-face into the gaps on either side of the poles, it would certainly appear to be more logical to place the short-circuited damping coils in these gaps, as the flux produced by the currents induced in them directly prevents distortion of the main field.

The combination of asynchronous and synchronous motor-generators suggested by Mr. Field for substation work should be a good one for substations of small and medium size: as Mr. Patchell has told us, this is precisely the form of substation he is putting down in connection with the City lighting. Of course the great objection to asynchronous motors is the heavy lagging current taken by them, which not only wastes energy, but causes demagnetising reactions right through the

Mr. Eborall. system, which greatly impair the pressure regulation. This is why synchronous machinery, which never need work with lagging current, is preferable for nearly every class of substation work.

Mr. Field refers to the use of "inverted rotaries," and describes what may happen in working unless proper precautions be adopted. Personally, I cannot see the use of such machines, for the extra complications brought about by their use are not balanced by the advantages obtained. Such machines are usually wanted in direct-current power-stations, a small portion of the load of which is situated at a distance too great to be conveniently supplied with direct current. Under these circumstances, it seems to me far preferable to put down either a motor alternator or a direct-coupled steam set for supplying the distant area, rather than a rotary converter, either liable to the troubles Mr. Field has described, or else working in a complicated manner.

Dr. Thompson also criticises my views as to the application of damping coils, mentioning that the A.E.G. of Berlin are using in their new 3,000-kilowatt machines the construction first put forward by Leblanc, of piercing the pole-shoes for the insertion of short-circuited copper bars. As the A.E.G. are the owners of the Leblanc patent for Germany, it is not surprising that they should employ damping coils in this particular way. I think I am right in saying that the only firms who use this form of damping coil are those who are directly interested in the Leblanc patents and constructions.

Dr. Thompson has somewhat misunderstood my remarks regarding the use of choking coils in connection with the long high-pressure feeders supplying current to the substations. Dr. Thompson has proposed these choking coils for another purpose, namely, for annulling the capacity of the feeders, the choking coils being connected in parallel with them. The choking coils used in Prague are connected in series with the feeders, and their purpose is not to annul the capacity of the cables, but to damp down the pulsations of current which are always found with synchronous machinery fed from a power-station in which slow-speed engines and direct-connected generators are employed. The pulsations of current in the feeders which would otherwise occur, due to irregularities in the turning moment of the engines, would have a very perceptible effect on the pressure regulation of the system, and are therefore objectionable if any lighting work is done directly from the polyphase feeders.

Dr. Thompson and Mr. Ferranti have referred to the direct distribution of power by means of polyphase currents—that is to say, without the aid of substations. I should be the last one to propose substations for converting the alternating current into continuous current for *all* classes of work, and this is clear, I think, from the text of the paper. But it must be remembered that at the present time induction motors cannot be regarded as being satisfactory for traction purposes, and therefore for this kind of work it is necessary to convert the polyphase current into direct current. It must be remembered that the disadvantages of three-phase motors (as at present constructed) for tramway and railway work are very great, and I do not think it is commercially possible to use them at the present

time for any but special cases, such as mountain railways, etc. There are the extra conductors, the heavy lagging currents, the difficulties of economical speed control, the question of acceleration and starting currents, the pressure regulation of the system, the inferior mechanical design of the motors (due to the small air-gap), which all have to be very carefully considered; and moreover, direct-current traction apparatus is thoroughly standardised, while polyphase traction apparatus is hardly out of the experimental stage. Mr. Eborall.

For industrial power work and for lighting and power there is no reason why polyphase current should not be utilised directly, but in many quarters in this country there is a strong preference for using direct current for these purposes, and consequently manufacturers are asked to equip substations with machinery suitable for converting the polyphase current transmitted from a distance into direct current for feeding into the distributing networks. On this account, and also because of the actual necessity for substations for traction purposes (for the reasons given above), the question of substation equipment is of interest and importance—hence the present paper.

In reply to Mr. Esson's first remarks, as to the behaviour of induction and synchronous motors when short-circuited, I would point out that this point is discussed in the second part of my paper; personally I find that there is very little difference between the behaviour of synchronous polyphase motors and induction motors when momentarily short-circuited.

I have not found it necessary to construct special starting boxes for induction motors to be used in substations, as indicated by Mr. Esson, nor do I quite follow his reasoning as to the necessity for this. Standard induction motors, as built by the leading firms, are usually sent out with starting boxes provided with five to nine notches per rotor phase, according to the size of the motor; this readily allows the motor to start with a current in accordance with the load. An asynchronous motor-generator will usually take about 50 per cent. of the full-load current at starting, the current rapidly decreasing as the machine gets up speed. Unless the polyphase generators are very badly designed, such a starting current would not affect the lighting circuits, however large the motor generators.

Regarding the question of the air-gap length in induction motors, referred to by Mr. Esson, I consider that with good workmanship it is easily possible, and perfectly safe, to work with the clearance I have named, namely, $\frac{1}{450}$ of the rotor diameter; and, moreover, there are hundreds of polyphase motors built by leading Continental firms that have been working for years with still smaller clearances. Mr. Esson is mistaken in stating that Continental practice is to allow air-gaps 50 per cent. greater than this—in this connection I would refer him to a paper I read last year on the subject, before this Institution. A larger air-gap than 0·1 inch with a 45-inch rotor would undoubtedly mean a low power-factor, however highly the stator teeth are saturated.

In reply to Mr. Esson, I would say that the pressure drop of the 500-kilowatt synchronous motor illustrated in Plates III. and IV. would be 5 per cent. if tested as a generator upon a non-inductive load; a

Mr. Eborall. smaller drop than this would be a great mistake with a synchronous motor, or for that matter in an engine-driven generator also, from considerations of parallel running. I regret having to disagree completely with Mr. Esson's remarks on this point—the few polyphase machines that have been made by English firms are not heavier than those of Continental make, and are not too well designed. It is for this reason that they are not bought, and not because they are too good (and consequently dearer) as stated by Mr. Esson.

I do not quite follow Professor Carus-Wilson's argument regarding the relation between the momentum of the rotating parts of synchronous machines, and hunting. My own observations tend to show, however, that the lighter the moving parts of such machines are, the better, and I may say that it is by no means difficult to prove theoretically that this must be so. For hunting is purely a mechanical effect, and the amplitude of the oscillations or swings is directly dependent upon the moment of inertia of the rotating part of the machine. Again, the lighter this part is, the more chance the damping coils have of checking the oscillations in their early stages, for the machine is more under control.

I think Mr. Cruise must have overlooked a considerable portion of the first part of my paper, for otherwise he would see that the points raised by him in connection with transformers have been discussed. I may add, however, that up to 100 kilowatts, a three-phase transformer will usually come out cheaper than three transformers each of one-third the output, in addition to being technically better, for the reason I have given.

In reply to the question put by Mr. Cruise regarding the pressure regulation of synchronous motor-generators, I may say that if the synchronous motors are well designed, they are quite capable of taking care of the load, in spite of the pressure variations at the ends of the feeders usually met with. As the speed depends only on that of the power-station engines, the only effect of varying pressure at the terminals of the synchronous motor is to alter slightly the power-factor of the latter, assuming, of course, that the variation is not sufficient to pull the motor out of step. In practice a slight amount of field regulation on the motor is all that is necessary to ensure proper working of the plant. For further information on this point I would refer Mr. Cruise to the paper.

In reply to Mr. H. L. Leach, the tachograph exhibited (which is a standard instrument on the Continent) is constructed by Dr. Horn, of Leipsic; it can be obtained from Messrs. O. Berend & Co., Limited, of London.

In addition to Prague, there are many Continental towns supplied with three-phase current for lighting and power, such as Dortmund, Strassburg, Mannheim, part of Berlin, part of Frankfurt, part of Paris, etc. Mr. Leach will find a list of these towns in Germany published at the beginning of every year in the *Elektrotechnische Zeitschrift* (J. Springer, Berlin), to which journal I would refer him, as he will there find all the information he wants in a convenient form.

Mr. Edwards's statement regarding the hunting of rotaries confirms

what I said in the paper as to the important part played by the engine governors. Mr. Eborall

Mr. H. C. Leake makes a good point regarding the setting of engine cranks. Placing the cranks of an engine at 0° or 180° rather than at any other angle is of importance, because then there are but two maximum and two minimum speed points per revolution against the four maxima and four minima which would otherwise result. Experience shows that it is these points which frequently give rise to such difficulties with parallel running, on account of their direct bearing on the resonance effect referred to by Mr. Leake in the fourth paragraph of his communication. With engine cranks at 90°, for instance, there is four times the probability of an interference effect occurring between the pendular swings of the generator magnet-wheel and the maximum and minimum speed points mentioned above, compared with the probability of this effect taking place with the engine cranks at 180°. It is for this reason that nearly all horizontal compound engines on the Continent have been standardised with tandem cylinders and one crank.

Of course, the given cyclic irregularity must not be exceeded and consequently a heavier flywheel is required, or rather, more metal has to be put in the rim of the magnet-wheel. With a large generating set, however, the increase of cost due to this is negligible in comparison.

As stated in the paper, it is best to get along with as small a flywheel as possible, partly because the combination of flywheel and governor inherently tends to hunting, and partly for the reasons I have given in the paper, and in reply to Prof. Carus-Wilson, relative to keeping down the momentum of the moving parts. For a given type of engine the amount of flywheel effect asked for by different engine builders in order to give the same cyclic irregularity under precisely the same conditions varies very greatly, as all dynamo builders know, and it is entirely a matter of careful designing of valves and proportioning and arrangement of the engine parts. Hence the remarks made on this point in the paper, which imply that engines for large electric power-stations should be designed first of all from the point of view of the attainment of satisfactory parallel running of the polyphase generators to be driven from them.

In further reply to Mr. Leake, the tachograms given in Fig. 9 were taken on an engine running alone with a small load on a water resistance. The flexible couplings used with the 500-kilowatt motor-generators, one of which is illustrated in Plates III. and IV., represent a standard arrangement with the manufacturers, and possess the advantage of preventing hot bearings should the foundations be defective, or the two machines be slightly out of line; and, moreover, should the safety devices fail on a heavy and persistent short circuit, the leather belt connecting the half couplings would snap (without flying out), thus possibly preventing a burnt-out armature.

In conclusion, referring to Mr. Leake's second paragraph, I may say that it is very well known that, from the point of view of parallel running, it is far better to place the generator between the cranks of

Mr. Eborall. the engine rather than at one end of the crank shaft, simply due to the twisting of the latter, which is accompanied by an increase of phase displacement between the E.M.F. waves of the generators running in parallel.

The President. The PRESIDENT: I will ask you to give your thanks to Mr. Eborall for his very excellent paper.

I have also to announce that the scrutineers report the following candidates to have been duly elected:—

Members:

Robert James Hatton. | Frederick Foley Robinson.

Associate Members:

William Joseph Bailey. | Frank T. Hanks.
James Henry Hamilton. | Arthur Hopwood.
Thomas Robert Smith.

Associates:

Karl B. Hearder. | Henry Scott.
Cecil Hodgson. | James S. Smith.

Students:

Charles Cuthbertson. | Horace Edgar Herring.
Sydney Elliot Glendenning. | Octavian Joseph Mackenna.
George Lester Hales. | Patrick J. Rice.
George Vose Stavert.

DUBLIN LOCAL SECTION.

At a meeting of the Section held at the Dublin United Tramway Company's Power Station, Ringsend, on March 7th, 1901, Professor W. F. BARRETT, F.R.S.E., in the Chair:

Reference was made to the great loss to the Section and to the Institution caused by the death of Professor G. F. Fitzgerald, F.R.S., the Chairman of the Dublin Local Section. Professor W. F. Barrett proposed:

"That our sincerest sympathy be extended to Mrs. Fitzgerald,"

and the Resolution, having been seconded by Dr. F. T. Trouton, F.R.S., and supported by Dr. A. Traill, S.F.T.C.D., was carried in silence, the members standing in their places.

MANCHESTER LOCAL SECTION.

(Paper read at Meeting of Section, February 12th, 1901.)

ON THE TRAINING OF ELECTRICAL ENGINEERS.

By JOHN T. NICOLSON, D.SC., M.Inst.C.E.

Electrical engineering differs from the other branches of the profession of the Civil Engineer in being based on theoretical principles whose application give predicted results which closely accord with those practically obtained. As Professor Perry said in his Presidential address delivered a few months ago: "Most of the phenomena dealt with by the electrical engineer lend themselves to exact mathematical calculation, and after calculations are made exact measurements may be made to test the accuracy of our theory. A completed machine or any of its parts can be submitted to the most searching electrical and magnetic tests, since these tests, unlike those applied by the mechanical engineer, do not destroy the body tested."

Although hardly true to allow the inference that all the tests made by the Civil or Mechanical Engineer are necessarily of such a nature as to "destroy the body tested," yet there can be no doubt that whilst electrical engineering is the youngest of the engineering sciences and arts, it has come clearly to the front in close physical accuracy of its theory; and in this department we have not been so notably troubled with a division into the two camps, of which we have heard so often, of those who believe in theory and those who believe in practice.

The reason for this difference from the civil, mechanical, or mining branches of engineering seems to lie in the circumstance stated by Professor Perry, as follows: "Electrical engineering owes its being altogether to scientific men, to the laboratory and deskwork of a long line of experimenters and philosophers. Even now the work going on in the laboratory, to-day, becomes the much larger work of the engineer to-morrow." It would thus appear that, in electrical engineering, practice has been largely directed by a consummate theory; whereas in other departments

theory has, at its best, only endeavoured to understand and explain practice.

This fact has an important bearing on the subject we have before us to-night; for it is obvious that the relation between the theoretical and practical development of a branch of engineering must largely govern the principles to be followed in methodising the training of the students of that branch.

The other distinguishing feature of electrical engineering, which must be carefully borne in mind in the same connection, is the unparalleled growth of electrical industries in the past ten or fifteen years, and their present increasing rate of development. So much is this the case, that the task of keeping the professional training of the students of this branch of engineering abreast of current practice seems almost a hopeless one.

This raises the all-important question whether it is within the province of engineering schools or colleges to impart technical instruction, properly so called,—to supply, viz., up-to-date information as to the practical details and processes of manufacture of machines, and to give instruction in such-like mechanical arts,—or whether it is their duty rather to confine themselves to the scientific principles that underlie engineering in general, and its several branches in particular.

I think the proper answer to this question has now been found in the general adoption of the laboratory as the proper adjunct and complement of every first-class school of applied science. Without the means of making experiments the study of applied mechanics was closely analogous to, and in fact was an extension of the study of rational or theoretical mechanics. There were then certain data conceded as founded upon professional experience, and the course of instruction was confined to the consideration of the results flowing from reasonings based on these data; and to the working of problems and exercises in the application of these theories which were intended to form an introduction to the actual office work of the engineer in practice. It must be allowed that much of this excellent work is still and will always be necessary. Resting on a strong foundation of mathematics, physics and chemistry, the knowledge of the engineer must always include such

pure sciences as those of kinematics, dynamics, hydrodynamics, thermodynamics, and electrodynamics. A sound elementary acquaintance with all of these is necessary, and a specialised knowledge of that one more particularly useful to the engineer in his own branch must be obtained. It is, for instance, quite hopeless to try to explain to a man who has no knowledge of dynamics, upon what principles one proceeds in endeavouring to balance a locomotive. No amount of laboratory experiment will enable him to dispense with a knowledge of the mechanical principles involved. Again, the fundamental principles of thermodynamics may not be of much use in helping a man to fix the size of the cylinders of a steam engine; but they will at all events keep him from wasting his time in trying to design a perpetual-motion machine; and they will show him how far he can hope to go in the direction of the improvement of his heat motors, or other energy transformers.

But the province of the laboratory in the scheme of engineering education is: first, to extend scientific knowledge by providing more experimental data; and, second, to show to the student the scope, value, and limitations of the theories he has studied in the class-room.

Without laboratory work the young engineer is in danger of supposing that an engineering problem has been solved when a certain mathematical solution has been obtained from a basis of given physical assumptions.

The *critical* or *engineering sense* is not developed in the class-room. The student cannot be expected to know which of the assumptions underlying his mathematical work is really close to practice; and which other, although the best that can be made, is far from being true. Since applied mechanics, or engineering, is not a complete science, but is constantly being revised as to its data and being added to as to its experimental laws, it is not sufficient to deal with it as with an abstract science having immutable laws and finally reasoned-out consequences; on the contrary, the young engineer must be trained to exercise a salutary scepticism as to all generalisations from experience, and to, as far as possible, prove things in detail for himself.

Reverting to the question of instruction in up-to-date engineering practice, it may be added as the third function

of the laboratory—and more especially of the electrical engineering laboratory—that it should contain machines and instruments of the newest types procurable, which may serve as object lessons on the general trend of electrical engineering design. To avoid becoming an old curiosity shop it will be necessary in most schools to rely upon the assistance of manufacturers who are willing to lend their recent patterns of machines to the laboratory for testing and examination purposes for a reasonable time, in return for the supply of the experimental data and results obtained from the machine under test.

We have referred above to two features which distinguish electrical from other branches of engineering. They were: First, the possibility of a closer approximation to practice in the theoretically predicted results of working; and, secondly, the extreme rapidity of development of this branch of engineering. It would therefore appear that, of the three uses of the laboratory in the school of engineering just mentioned, viz., the obtaining of new experimental data; the cultivation of the critical or engineering faculty in the student; and the exemplification of recent practice in design; the first and last are of greater importance in electrical engineering laboratories than the second. Inasmuch as the more closely a theory already seems to approximate to the actual phenomena obtained, the smaller is the need for overhauling this theory by checking its results by means of laboratory work. Yet one might argue that this close agreement only shows that the smaller and more intricate variations of the natural from the assumed laws, are nearer to discovery; and that a closer examination and study of the phenomena, and more refined experimental work have become necessary.

In any case, the personal verification of the data of his subject is very necessary for every student as a good working foundation to build from, and as being the surest way of obtaining a real knowledge of and love for his adopted profession. According to Professor Perry's address: "There is one qualification which the electrical engineer must have, and without which all other qualifications are useless, and if a man has it no other qualification is supremely important, and this absolutely indispensable qualification is that a man should love to think about and work with electrical things."

I would wish to modify this rather sweeping remark by quoting another sentence from the same discourse, that, viz.: "An electrical engineer must have such a good mental grasp of the general scientific principles underlying his work that he is able to improve existing things and ways of using these things."

This latter qualification, a knowledge of theory, he must acquire by private study and from his college lectures; the former will be best inculcated by experimental work in the laboratory.

I am, I suppose, to-night expected to state what I should consider the best or ideal training one would give to a youth entering the electrical engineering profession if the choice were open.

In reply I say, in the first place, that in the case of a really clever student whose heart is in his work, it is my experience that his course or mode of training matters very little. Even if he be trained on a very bad system, or not trained at all, he will acquire all the knowledge and experience he needs in spite of, and in the teeth of the bad training. The desire to know, and the love for his subject is enough for *him*.

But for the ordinary youth of mediocre abilities, whose inclinations have to be carefully coached in the right direction, and whose all too easily flagging energies husbanded as much as possible, the sequence of his physical and mental treatment is of real importance.

In the first place, I hold strongly the opinion that, after leaving school, the boy who intends to become an electrical engineer should first spend at least two years in the workshops of a *mechanical engineer*. Here he will learn the elements of smithing, moulding, pattern-making, fitting, machine-work, and erecting. In this time he cannot help picking up the names and appearance of the common implements and processes fundamental to all kinds of engineering practice.

A boy of sixteen, having just left school, has for a time had enough of book-work, and will turn gladly and with great advantage to the complete change the workshop affords him. Here I may seem to be at variance with Professor Perry when he says: "Much of the evil we suffer from is due to our average young men being pitchforked

into works, where they get no instruction, as soon as they leave school. If ordinary school education were worth the name, and if schoolmasters could be brought to see that we do not live in the fifteenth century, if boys were really taught to think for themselves through common-sense training in natural science, things would not be so bad. But the average boy leaves an English school with no power to think for himself, and with less than no knowledge of natural science, and he learns what is called mathematics in such a fashion that he hates the sight of a mathematical expression all his life after.

"And what is the result? English engineers do make a wonderfully intimate acquaintance with the machines and tools that they work with; but, when it comes to the manufacture of new things, they do it by fitting and trying, by quite unnecessary expenditure of money through trial and error. A machine is made and tried and then another better one, until a good result is arrived at. And this method did well enough in the past, and would do well enough in the future if only we had not to compete with foreigners who can really calculate."

I would point out, however, that the workshop course here proposed is merely the preliminary or first part of the student's professional training. If he has left school with the usual stereotyped stock of Euclid, algebra, and elementary physics and chemistry, I would have him take mathematics, physics, and chemistry classes in the evenings; but more especially mathematics, during these two years of workshop practice. Classes ought to be everywhere organised to teach mathematics for engineers in the manner proposed by Professor Perry, so as to enable such a boy to learn as much useful mathematics as possible in the short time he has available.

I should advise the addition of another year of workshop practice in the shops of a dynamo manufacturer, if time permitted; but this will more usually have to be supplied by the laboratory of the college through which he must pass.

I have always found it extremely difficult to arouse, in the case of boys coming directly from school to the professional college, a lively and intelligent interest in their subjects of study.

Even with the help of a large and well-equipped college

workshop, they cannot get the relation of their work to engineering practice properly established. They fail to realise the important bearing the theoretical work they are doing has upon their future careers, unless their curiosity has been first stimulated by a period of probation in the workshops and a spirit of inquiry fostered by long, continued contact with actual engineering practice.

I have had some considerabe experience in these matters, having served a four years' apprenticeship, worked in a number of drawing offices, studied in one and taught in two other Universities; and my experience, both as a learner and a teacher, lead me to recommend most strongly that, whenever possible, a period of workshop practice should intervene between school and college.

Having, then, put in two years in a mechanical engineering workshop, our ideal student ought to enter an engineering college at about the age of eighteen, and he ought to study there for not less than three years.

The first year of this college course will usually have to be spent on mathematics, physics, chemistry, dynamics; mechanical, geometrical, and freehand drawing; and the study of French and German, which is so necessary for enabling him to read foreign technical literature.

In the second year the electrical engineering student must specialise in the physical laboratory in the direction of electro-magnetic theory. He must study the magnetic qualities of iron and the hysteresis loss; and in doing so he must learn the construction of the instruments such as the galvanometers, voltmeters, and ammeters he uses in his work, and the methods of their calibration. All this experimental work should, of course, proceed hand in hand with instruction in theory and numerical exercises in the classroom; where he should be working at electro-magnetism and the theory of the direct-current dynamo.

In this same year he must apply a considerable portion of his energy to the study of thermodynamics and hydraulics, and their application to steam and water power plants; and he should devote great attention to the study of machine design and mechanical drawing. The electric engineer must have a special knowledge of applied electricity; but he must be above all an *engineer*, and not a mere electrician.

In his final year, three-fifths of the student's time should be spent in the laboratories; one-fifth in the electrical engineering designing-room; and the other fifth upon lecture courses connected with his laboratory work. About one-third of his laboratory time should be devoted to experiments on the strength of materials, on the simpler hydraulic phenomena, and to trials of steam engines and boilers. I think that at least thirty days of eight hours each should be spent in this way in his third year. Another third of the time spent in the laboratory in his last year would be occupied in completing the elementary electrical laboratory course he began in his second year. He would, after completing his work on magnetic testing, begin a study of the dynamo. For this purpose the laboratory would probably be provided with a number of direct-current dynamos of various types and styles of construction, of from two to ten kilowatts capacity, which can be operated either as dynamos driven from a constant speed prime mover, or as electric motors.

Using the ordinary commercial instruments such as voltmeters and speed counters, he should determine the strength of the fields of these machines when the armature windings are known and the speeds and pressures measured. He should compare the results obtained from the machines when running with those calculated from their dimensions. This will give the student an idea of the control which his class-room theories require from practical results, and to what extent uncertainty enters into his estimations. Tests of the magnetic circuit of dynamos, the regulation of dynamos and motors with different forms of field winding, characteristic curves, and efficiency testing should naturally follow; and it is an excellent plan to make the student draw up tables and make curves of the variations in the principal proportions of machines of different types and sizes, in order that he may obtain an idea of the changes involved by particular conditions of service and output.

The data of this kind available in an engineering school are seldom of the latest, unless the teacher spends his summer in obtaining them. The instructor in electrical engineering has, as already mentioned, the special difficulty of the newness and constant development of his subject to contend with; but if he follows the practice of every

year visiting the plants of the manufacturing companies and typical light and power stations, information is obtained which cannot be found in engineering literature, and which has the highest value for educational purposes. The cultivation of close relations between the college and the practising profession should, indeed, be part of the duty of instructors, and ought to be eagerly reciprocated by the members of the profession as one of the surest ways of meeting foreign competition. The professional status of the teacher of engineering in this country is not by any means so high as we find it abroad. In the *Electrician* of February 1st I read: "It is announced in *Elektrotechnische Mittheilungen* that Herr von Dolivo-Dobrowolski, chief electrician of the Allgemeine Electricitäts Gesellschaft, is shortly going to Petersburg to take over the direction of the new Government Electro-technical Institute there. The same journal states that Herr Görges is giving up his position as engineer-in-chief of the firm of Siemens and Halske to fill a professorship at the Dresden Polytechnic." I have yet to learn of any appointment in a college or technical school in Britain whose attractions could induce its acceptance by the engineer-in-chief of any of our great companies! The fact is, the Germans and Russians have come to realise the value of the scientific and technical training they provide in their polyteknikums to the national industry and well being; whilst in Britain we are still content to muddle along in our honest but stupid old way.

To return to our third-year student. The remainder of the second third of his laboratory time will be filled up by work in electro-chemistry and alternate current work. The former subject seems now to demand a laboratory equipment almost on a par with that of the dynamo-room itself in a first-class school. The latter is usually better represented, and the enormous importance of polyphase currents in power transmission renders it necessary that every effort should be put forth to give sound instruction in this field. The effects of inductance and capacity are at the root of a large proportion of alternate-current phenomena, and the fundamental studies in this department accordingly have reference to the study and measurement of these properties. The object of the teacher must be to convey to the electrical student as lively and

practical a working conception of inductance and reactance as that usually given him of Ohm's law and its results. The student should have at his disposal a number of coreless solenoids for the direct measurement by ammeters and voltmeters of their self-inductances, using an alternating current of known frequency; and the comparison with their mathematically determined coefficients. He should also be able to make, by the use of ammeters and ballistic galvanometers, the direct measurement of mutual inductances; and to compare self- and mutual-inductance with capacity. He should then extend his measurements to circuits with iron cores. Carefully wound long and short solenoids having known constants; condensers of known capacity, bridges, alternating-current ammeters and voltmeters, the ballistic galvanometer and secohmmeter are the instruments he will employ most at this stage.

The student should then pass on to the study of the alternator and to single-phase currents. The wattmeter and the alternate-current curve-tracer must be put in his hands; and the relations of the current and pressure waves in circuits must be studied from the curves, as well as from measurements of the true and apparent energy in the circuits. This study is finally applied to transformers of various types of construction. For the study of polyphase currents it would seem best to have in the laboratory a rotary converter, so that currents of variable frequency may be obtained. Induction motors of representative types of construction ought also to be available.

A large part of the work here specified on alternate-current machinery must, however, be relegated to the next division of the laboratory work of his final year, when he will have more time for uninterrupted experimental work, and be left more to his own initiative. The great matter is to instil habits of personal investigation and critical study into the mind of the young engineer, so that his college course may form really a graduated introduction to the work of his whole life.

This last portion of his laboratory time should be devoted by our embryo electrical engineer to what is, in America, called "thesis" work. This is of the nature of an experimental research, carried out either by the student himself or by a small group of students of which he is one.

Very much valuable information has been obtained in American colleges in this way, regarding the various types of new apparatus continually coming out; and it is found that the students learn, in the course of such work, to assume responsibility by being in a large measure left to their resources. Such investigation usually requires either special apparatus or the loan of new types of machinery; but good work may also be got by making progressive tests of an operating plant either in the college or elsewhere. The interest and even enthusiasm with which this part of the work is taken up and carried on by the students is very striking and encouraging, and was such as to lead the writer to adopt the "thesis" system in his late laboratories at McGill College, Montreal, although quite contrary to his preconceived prejudices against the utility of allowing undergraduates to undertake research work.

With regard to the one day per week of the student's last year which was told off for work in the electrical drawing office, my friend, Professor R. B. Owens, of McGill College, has found it an excellent plan to take up the design of a complete line of machines to meet given commercial conditions. Each student takes one; and the advantage of having all the students in the class working on machines of the same type, but of different dimensions, is that by comparing notes they are able to see clearly the change necessitated in the dimensions, as the output, or conditions of running, vary.

A set of both direct and of alternate current machines should always be taken up. A good plan is then to submit the data compiled, and the drawings prepared, to the criticism of some one whose business it is to design machines for the maintenance of a reputation and the earning of an income on money invested in the manufacture of electrical machinery.

In this way the attempt may be made to impart to the student information possessing a real market value, without sacrificing the study of broad principles to unnecessary detail.

An important expedient for bringing the electrical engineering college into close contact with the ever-varying practical development of the subject, is to obtain the services of specialists in the several fields of current work, in giving courses of lectures on the status and probable

development of their special line of activity. Courses of from six to ten lectures each, upon which the student should be examined, as upon work given by the ordinary instructors, are best adapted for dealing with such special topics. One or two lectures by a distinguished engineer, although interesting, do not meet the requirement.

Another most important study which ought to be mentioned in this connection is what is called by the Germans, "Wirthschaftlichkeit"; and which may perhaps be rendered the "economics of engineering design." Its object may be most easily explained by taking an example from the work of an American College which is due to my friend Professor Owens.

It was required of every electrical engineering student in this College, that, towards the end of his course, he should figure out the design of either a lighting or street railway plant. A number of scale drawings of towns of various sizes were available, and from known or assumed conditions the position of the station was assigned. Then, in the case of a lighting plant, the locations of the individual customers was taken as given, with particular load diagrams for each. From these isolated diagrams the nature of the station load was determined, and the machinery and circuits laid out. All the circuits were calculated and were shown on the map, together with poles and the more important accessories. Outline plans for standard machines were readily obtainable, and the station was arranged by their aid. Full specifications for the plant were then drawn, definite as regarded the results to be obtained, but impartial as regarded different types of plant. Lastly, a bill of material was made out and the costs estimated for some one type of standard machinery, using price lists and allowing for labour; and the expense of operation and maintenance, together with the income necessary to render the installation a paying investment, were determined. Such plans and estimates were then checked by a constructing engineer whose business it was to be in touch with such matters.

This department of study, which really constitutes the daily duty of the designing engineer, has been to my knowledge almost wholly neglected in all save one or two German and American colleges. Such a worked-out example as the above places in due perspective the relative value of the

various portions of the pupil's whole curriculum. Hitherto we have mostly been content to discuss with all elaboration the design of our machines in regard to their general convenience and adaptation to their purposes, keeping in view simplicity and safety of operation, easiness of adjustment, and facility of repair ; we have also exhaustively treated the elements of strength and rigidity, and the balancing of the rotating or other moving parts ; in some instances the ideas of harmony of proportion and of elegance of detail has even been entered into ; but very seldom have the really vital questions of cost of construction and total cost of production of different designs, in relation to the respective expenses of their maintenance for operation and for repairs, and of their durability, been duly approached in the professional college or school. Yet these are the governing factors in the everyday settlement of engineering problems !

The course of training for an electrical engineer, which has been somewhat hurriedly, and I fear incompletely, sketched in the above remarks, nevertheless outlines the curriculum which a not inconsiderable experience in such matters leads me to recommend as being best adapted—not in any sense to produce a complete electrical engineer—but to impart to a youth of moderate ability and unflagging devotion the capacity to follow with success that arduous calling. It must be recollected that the British engineer of the new century will need not only to know and to be able to use that which has been perfected by his predecessors ; but to be continually experimenting and improving upon what already exists, to be devising new lines of activity, and to be discovering fresh fields of operation, if we are to maintain not merely our industrial supremacy, but even our national independence, in the tremendous struggle for commercial existence which is now impending.

In conclusion, I would press upon the members of this Institution the strong conviction I hold of the expediency, from the point of view just referred to, of at once establishing some arrangement whereby the more eminent young employees of our manufacturing houses may be enabled and encouraged to return, for periods of months at a time, to the laboratories of their Schools or Colleges, for the purpose of spending their whole energies in the prosecution of industrial research for the benefit of the firms employing

them. This system is already partly in vogue in Germany and America, and has produced most gratifying results. But this, and all the other questions in regard to the proper education of our young engineers, is entirely in the hands of their future employers. If the leaders of British industry do not realise the national significance of such higher scientific training as is here proposed, it is futile for the heads of our Colleges and Technical Schools to seek to thrust forward their projects in their despite.

Mr. Rhodes. Mr. W. G. RHODES thought that Dr. Nicolson was aiming at too high a standard, as the majority of students in electrical engineering are unable to attend full courses of instruction, and can only obtain their theoretical knowledge from evening classes. He considered that Dr. Nicolson was right in advocating a two years works' experience for those who were in a position to acquire it prior to entering upon their college course of theoretical instruction, for the reason that the latter then appealed to them as being of a more concrete nature and of more practical importance than would be the case if they were to proceed direct from school to college. Mr. Rhodes also regretted the fact that the majority of teachers of electrical engineering were without works' training themselves, and consequently to a great extent unable to impart the theory to students in the manner best calculated to show its bearing upon actual practice. Instead of appealing to their students from a physical and practical standpoint, the real issues were only too frequently buried in a mass of mathematical symbols quite unintelligible to the ordinary student.

Mr. Wilson. Mr. W. WILSON said the question touched upon was one of the utmost importance to the profession. He thought it might have been advisable for Dr. Nicolson to specify that he was referring to an ideal training, which was almost impossible at the present day with the students they had to deal with. The whole question was involved in a much wider one. For the past few months many educationalists had been trying to see what they could evolve out of the chaos of secondary education before talking of the higher training of the pupils in the technical colleges. The material they got at the technical schools was very indifferent indeed. He was not talking about evening students but day students, whom they hoped to find by and by in larger numbers in the technical schools. They hoped to get secondary education placed on a proper basis, and to train youths to think in other languages as well as their own; then they might hope to do something in Dr. Nicolson's course, but at the present time it was an ideal one, and with the present material almost hopeless. A course of that kind was only adapted to two or three places in the country where all the best youths of a large area might be sent. They might have a central technical college in London, and another in Lancashire for electrical engineering, and another for textile industries; but the whole subject was involved in the

Mr. Wilson.

question of secondary education. He would draw especial attention to the closing remarks of the paper, namely, that the whole matter depends on the leaders of British industry. It was impossible to get youths to serve an apprenticeship at the age of seventeen. He had heard a large engineer say, "We do not want well-trained men; we want workmen, men who are machines." Now, when you have got to deal with certain large engineers of that type, how are you going to give the training mentioned in the paper? It had been said that if you could produce a Faraday once in a century the technical colleges would justify their existence; but they were a very long way from that. There was not much, however, to cavil at in the paper; it was an admirable one. There was only one point, viz., the student after leaving school was to go for two years into works and then go back to a technical school. The British employer of labour, however, did not give much assistance in that direction. In a large majority of cases it was impossible to get a youth into works at all unless he was to stay for some length of time. If he intended to leave in two or three years, the knowledge he would be able to pick up in the works would be very small indeed. He wished sincerely that they could aspire to the ideal placed before them in the paper; they were trying to do so as far as possible, but they were a very long way from it. With the training given in evening classes they could not expect to produce such an engineer. They ought to get the pupils to come to the technical schools in the daytime for a considerable period, and then they might be able to adopt the training given in the paper.

Mr. Wordingham.

Mr. C. H. WORDINGHAM said the paper was almost wholly one for the teacher. He could not claim to be a teacher, but he had found that a municipal engineer was looked upon as a provider of universal information, and parents frequently consulted him as to their sons; he had thus been led to give some little consideration to the subject. He took it that Dr. Nicolson was describing the training of electrical engineers, and not the imparting of instruction to workmen. The two were different: you could no more train an electrical engineer by means of evening classes than you could train a doctor in that way. If a man is to make electrical engineering a profession he must enter it by means of a proper course of study, and by devoting a considerable number of years to that study. He, therefore, did not propose to refer to the question of evening classes. Mr. Rhodes had very clearly pointed out the enormous difficulties connected with them. He who derived much benefit from evening classes was a very exceptional man: he had met men who had, but they were exceptions. As regards the ideal course of Dr. Nicolson, he agreed with him practically in every particular; the course sketched out was an admirable one, but he did not agree with the order in which the course was to be taken. Dr. Nicolson very strongly advocated that a boy on leaving school should enter works for two years, and then get a theoretical training. In his (Mr. Wordingham's) judgment it was better for a boy to go straight from school to college for three years than to enter works at once; after the college training was over he should get his workshop experience. Learning

Mr. Wordingham.

was very largely a matter of habit. A boy when he left school had the habit of learning, and was used to discipline. The college was merely a development of his school life, and a student would find it much easier to learn then than when he had broken off these habits. Another reason was that the student appreciates very much better what he learns in the workshop if he already has a good knowledge of the principles of the work on which he becomes engaged. A great deal of the practical work is wasted if the boy does not know what he ought to look out for. If he is acquainted with the principles, he knows what he may expect to meet with in a concrete form. Another reason was that the surroundings into which a boy is brought in a workshop are not altogether desirable; a young man is very much better adapted to resist the influences to which he is exposed in works than is a boy fresh from school. Another point was that when a young fellow went into a workshop he got into contact with people who would afterwards employ him, and he was more likely to get a job and become a paid servant if he could go straight on than if he had to break off and go to college. He thought Dr. Nicolson was very right in pointing out that a general engineering training is vital; an electrical engineer must be first a mechanical engineer and afterwards an electrical engineer. The laboratory training recommended was good, and, besides the advantages enumerated by the author, enabled the student to get in an actual concrete form the conceptions obtained in his reading.

Mr. Guy.

Mr. ARTHUR GUY said he agreed with Mr. Wordingham that the engineering student should go direct from school to the technical college, because he is then more addicted to study, particularly for continuing his mathematics, which are the keystone of advanced electrical studies. After spending two or three years in the engineering course at college, he should then enter some good mechanical engineering works and serve his time for, say, four years, giving two years to the lathe, fitting, and erecting shops, one year to the pattern shop, and one year to the drawing office; he could then, finally, enter some electrical works where heavy machinery was turned out, and so obtain an intimate knowledge of the designing and construction of the same. In this last place he would be in a position to demand a moderate salary: two years would suffice for this. Then the total time spent would be—

Technical College	3	years, costing, say	£350
Mechanical Shops	4	,, ,, ,,	400
Electrical Shops	2	,, at a salary.	
Total	9	years, and cost ...	£750

It thus seemed to him that it was an expensive training to turn out a thoroughly qualified electrical engineer, having both a sound electrical and mechanical knowledge in addition to a fairly good grounding in general physics and mathematics; and, like any other profession, it meant a considerable outlay in both time and money even when the necessary ability to benefit by the same was granted. Consider what a Corporation electrical engineer had to deal with. Beginning with the boiler-house and flues, he required some knowledge of structural work

and building material; the construction of boilers, pumps, economisers, &c., and how to maintain and repair them; the analytical commercial value of different kinds of fuel; the scientific bearing of heat-energy on the fuel in respect to its proper combustion; the treatment of water used in the boilers—a very troublesome problem; the advantages between hand-firing and mechanical stokers; the proper management of the boilers so that the highest efficiency and longest life were secured, and so on. Turning our attention to the engine-rooms, our electrical engineer should be well acquainted with the construction and maintenance of engines, both high and slow speed types, be able to detect faulty running and remedy same, and to tell how an engine is performing its work by a mere glance at an indicator card. All this was required before the engineer's own particular branch of work—electricity—was brought into question; and here the field of application was almost boundless—the different methods of generation and distribution of electric energy—direct and single-phase and polyphase currents—economics of cable-laying—difficulties concerning insulation and current leakage—systems of electric traction and power distribution. He must be prepared to study and advise upon the most suitable methods respecting the requirements of his own particular district. Beyond all this theoretical and practical knowledge of his work, our electrical engineer must have a reasonable share of business acumen in dealing with commercial matters; so many things cropped up in the outside world that required good judgment, and it was experience alone that would carry him through. Of course men of such attainments as he had defined should and did command large salaries, and, considering the large amount of money appropriated to electric undertakings, it would be the worst possible policy to engineer them on the cheap. Mr. Guy.

Coming now to the higher training in science and technology so strongly advocated by Dr. Nicolson, he (Mr. Guy) was afraid there were very few men who could follow out such a course as Dr. Nicolson had sketched, since this higher or advanced course of studies should, in his (Mr. Guy's) opinion, come after our engineer had finished his time in the mechanical shops. They could not all be budding Professor Perrys, and Dr. Nicolson's reference to Professor Perry reminded him (Mr. Guy) that he had the honour and pleasure of being in his mathematical class for two years when a student at Finsbury, and he could well recall his earnestness in impressing upon the class the vital necessity of a good mathematical training. The study of electrical science was, to his mind, limited to a great degree by the student's knowledge of applied mathematics; and how many of them got on all right when dealing with direct currents, but as soon as they began to dive into the action of alternating currents came to a standstill, and found progress difficult? Dr. Nicolson certainly aimed high, but as he (Mr. Guy) mentioned at the beginning, there were the factors of *time*, *money*, and *ability* to be dealt with; and, finally, when the trained engineer took his place in the industrial world to earn his living, he had still to seek the touchstone of success.

Dr. CHARLES H. LEES said he congratulated Dr. Nicolson on Dr. Lees.

Dr. Lees. the completeness of the course he had sketched out, but he was afraid it was a more ideal one than could be carried out just now. The early training of the students they were in the habit of getting at a technical college was so deficient, that they were in most cases incapable of following such a course. If at some future time the early training of intending students were improved, the colleges ought to turn them out after a three or four years' course of that kind, men of the highest class. Whether they would or would not attain to that ideal in the next twenty years was a matter of doubt. He would recommend the student to go direct from the school to college, partly because the break in his educational life which would occur if he spent two years in a works would render him unaccustomed to acquire new knowledge, and partly because a boy going direct from school to works is of little use there, and is put on to work of a purely mechanical kind, which gives him a distaste for a subject on which his future career depends, and in which he ought to take the greatest interest. He thought it would be better for a boy when he leaves school to go to college, spend three or four years there, and then go into a works. It was, however, impossible for a college to provide all the information the electrical engineer required when he got into commercial life; and he thought certain points to which Dr. Nicolson referred, *e.g.*, the cost of the construction of different types of machines, should only be gone into superficially, as there were in such cases many details to be considered which only a person intimately connected with works could be well acquainted with. He considered Dr. Nicolson's course in its main features an extremely good one.

Mr. Gee. Mr. W. W. H. GEE said that after an experience of ten years in connection with the Owens College, and a further experience of ten years at the Manchester Technical School, he considered that the most important suggestion of Dr. Nicolson was embodied in the last paragraph of his paper. It was most desirable that young men in works should have the opportunity of returning to the Technical School. Even a few months would be of great advantage to them. He found that such students learnt very rapidly the parts of the subject which in their previous studentship they only partially understood. This was particularly the case with reference to the difficulties presented by alternating currents. He was glad to say that one local firm had already made an arrangement by which young men should come back to the Technical School from their works. He ventured to say that the experiment was likely to be a success.

Dr. Hopkinson. Dr. E. HOPKINSON said: With regard to the time in a boy's or young man's career which he should devote to obtaining workshop experience it appeared to him that most of those who had taken part in the discussion had looked at it mainly from the teacher's point of view. The teachers in our technical schools not unnaturally liked to have young fellows who had the advantage of having been a year or two in works; they were older than the average of their students, and were better material from a purely scholastic standpoint. He (Dr. Hopkinson) looked at it from a somewhat different point of view; he did not aim at turning out a good scholar merely, but he wanted to turn out a

Dr. Hopkinson.

well-trained practical man who could make his own way afterwards; thus he found himself in disagreement with Dr. Nicolson, and in entire agreement with Mr. Wordingham. For a boy to leave school at the age of sixteen and to enter a workshop with the idea of returning to school or college after an interval of two or three years (he was speaking of those whose means would allow them to continue their education in one form or another till a fairly late period of life) involved a break in his scholastic course and in his habits of learning which was a serious matter, and often had disastrous results. If he purposed proceeding to college or to a University, he was certain it was a mistake for him to have a break between school life and college life. He had known many men at college or the Universities who had gone up at the age of twenty-three or twenty-four who were too old to associate on equal terms with their fellow-students, whose school habits and school acquirements had grown rusty, and who had been consequent failures. On the other hand, he had known but few cases of University men, with health and energy and devotion to their profession, failing in their subsequent careers. Going through the works of the General Electric Company at Schenectady some months ago, his guide pointed out to him a dozen young men working at the bench who looked particularly smart, and, when asked who they were, said, "These are our University men; they have taken a University degree; these are the men we like best." Their school and college career had been continuous up to twenty-two or twenty-three years of age, and these were the men the American manager thought his best material. Although honour was due to those who had made it easy for some apprentices to break their apprenticeship and go back to school, he did not think it was right in principle, except in a few cases where a boy of exceptional ability had had to leave school at sixteen to go into works with the idea of earning his own living. In a case of that kind there might be advantage justifying return to college or a technical school after or during apprenticeship. Another reason why he deprecated the student leaving school at the age of sixteen, and then going into works, was the great strain on the physical system. It was very hard for a growing youth of sixteen to work from six in the morning to six in the afternoon and then to settle down for two or three hours' book work in the evening; a boy at that age ought to have more time for physical and mental recreation. We had to consider the health and physical robustness of our engineers as well as their mental training. Referring to a remark of Professor Wilson's as to the difficulty of finding places for his students in works, he had no doubt the difficulty existed. At the present time there was a marked want of equilibrium in the whole electrical industry as regards employment. Its development had been so rapid, attracting such great numbers of young fellows, that, as a matter of fact, the supply of youths was far in excess of the demand for their services. Although Professor Wilson was conscious of the difficulty, he (Dr. Hopkinson) might say that in his own works they had not less than two hundred young fellows, all of whom in one form or another were pursuing their education, some attending classes at the Salford Technical Institute, others at the Manchester Technical School,

Dr. Hopkinson. at the Owens College, or at their own school established in connection with the works.

Mr. Joyce. Mr. S. JOYCE communicated the following:—I must congratulate the Institution on receiving such an excellent paper on a very important subject. Dr. Nicolson occupies at the present time a very important position as Technical Adviser to the Manchester Corporation, and the success of their new technical school and the future of technical work in the district depend in no small measure upon him. There is much in his paper to discuss, but the time at my disposal will only allow me to touch upon a very few points. Speaking both as a lecturer to technical students and as an employer of technical men, there is much in his paper that I can agree with. Dr. Nicolson is quite right when he says our difficulties do not lie with the really clever student; but I cannot agree with him when he says that a boy on leaving school should first spend two years in works. Our ordinary school systems are so defective that the average youth of sixteen leaves school not only ignorant of much, but with his mind sadly warped by long application to obsolete matters dealt with by obsolete methods. On the one hand he is regarded as beginning to be too old to enter works with much prospect of success, and on the other he is, as a rule, hopelessly unfit to take up really serious work in a Technical School. But I am sure, from very sad experience as a teacher, that after two of his best and most developing years in a factory, starting perhaps at six in the morning, and spending the most impressionable years of his life with, in the main, ignorant, however well-intentioned, men, the lad returns to the school with his mind stunted, and regular habits of thought become difficult by long disuse. I have hardly known any exceptions to the rule that such students are a long way behind their fellows, though generally older.

Long experience of both sides of the question convinces me that a combination of the half factory and half Technical School is the really right thing, and until our manufacturing firms realise this we shall not make the true progress we all desire. At the present time the most successful students are those whose days are spent in our factories, and whose evenings are spent in our Technical Schools. But such work is only possible with good results to the favoured few who can stand the strain of burning the candle at both ends, and the success is in any case limited by the brevity of the time actually devoted to training.

The concluding paragraph of Dr. Nicolson's paper puts the matter in a nutshell, and I shall be glad if the paper and discussion may lead to some arrangement being come to whereby the training of our future engineers may be the united work of our Factory Managers and our Technical Schools.

Dr. Nicolson. Dr. J. T. NICOLSON, in reply, said that the course he had proposed had been objected to upon two main grounds. First, because of its being impracticable at the present time; as when Mr. Rhodes, Mr. Wilson, and Dr. Lees said that such a course could not be carried out with the students now available in technical schools. To this he quite agreed; but such statements only showed how great was the necessity for changes being made in the *matériel* passing through the schools

and in the character and scope of their work. In no technical school, worthy of the name, in America or Germany would a curriculum of a less thorough or comprehensive nature than the one he had proposed be accepted as qualifying a man for the profession of an electrical engineer. If, therefore, such a course was impracticable, it simply meant that the employers of this country were not alive to the importance of the matter as were those of the above-mentioned countries. It was, in his opinion, high time that our employers, with whom lay the ultimate decision in such matters, should fall into line with those of other countries, and make arrangements which would enable the best of their young employés to take advantage of the instructional facilities which a few educational authorities in this country were now able to afford. He believed that, at the cost of some inconvenience, and even some little monetary loss, the supremacy, if not the very existence, of the electrical engineering industry in this country could only be maintained by the careful training of our best young men along the lines laid down in his paper, which had been found to give such extraordinary results in foreign lands. He was afraid that many of our leading engineers were too well satisfied with themselves and with the successes they had achieved, to trouble much about the changed conditions under which their successors would have to face foreign competition. In answer, therefore, to the criticism that the course he proposed was too ideal, he could only strongly reiterate his own belief that unless it were quickly *realised* and carried out this country would be left behind in the industrial race. Dr. Nicolson.

The second ground of objection taken to his proposals was that it was not only impracticable, but inexpedient, that a period of workshop training should precede the college course of the future electrical engineer. He regretted to find himself at issue on this matter with such men as Dr. Hopkinson, Mr. C. H. Wordingham, Dr. Lees, and others who had spoken. He was afraid that they had not had the experience on this question that he had had the advantage of. He (the author) had found that the men who were best able to take advantage of such a course of study as that indicated in the paper were those who had spent some time in practical engineering work. The raw lads from school were generally outclassed by such students, as the former failed to realise the important bearing the theoretical work had upon their future practice; whilst the latter, whose curiosity had been stimulated in the workshops, fastened with avidity upon the mental pabulum placed before them.

There would, he believed, be found to be an important difference between the course described in the paper (with which he had had the experience just referred to) and that which his critics probably had in mind when advocating the immediate transference of the student from school to college. Whilst it might be to some extent true that a curriculum consisting largely of bookwork would be entered upon with more facility by boys fresh from school than by lads whose wits could only have been kept sharp by attendance at evening classes, it was not, in the author's experience, true when a large proportion of the college work was carried out in the laboratory. When it came to carrying out

Dr. Nicolson.

experiments, where resourcefulness, initiative, and a sense of proportion played a great part, the students who had had a practical training in the workshops had an enormous advantage; so much so that whilst the bright schoolboy often came out first in the junior or preparatory years, the shrewd mechanic generally overhauled him before the end of the course; and as a matter of fact, there was no comparison between the two classes of men as to fitness for a position of trust when leaving the college.

It might, no doubt, be difficult to carry out the scheme in the way he had proposed; but he agreed with Mr. Joyce that it ought to be possible to arrange, as the next best thing, a half and half course; and he believed that the Manchester Association of Engineers were now actually considering the matter along these lines by a committee of their Council.

Would it not be possible for the employers to pick out a few of the best of their apprentices—say in the second year of their (five-year) apprenticeship—and give facilities for them to attend college during the winter, whilst working the summer six months in the works. He (the author) was sure that an industrious boy of good ability would be able to not only keep up what he had learnt at school, but (between the ages of sixteen and eighteen say) add sufficient mathematics and mechanics to enable him to enter upon the college course in a state of sufficient preparedness to cover the ground sketched out in his paper in three winter sessions of six months each.

In return for the advantages thus afforded him the student should be under agreement to stay with his employer for a certain number of years after the end of his apprenticeship; and apart from the ultimate advantages to the profession of such a training, he (the author) believed that a substantial and immediate practical benefit would accrue to the employer by the adoption of certain practical research methods it was hoped to establish at the new Municipal Technical School, Manchester. There it was intended that the last two or three months of the course should be spent by the student in a research on any question in which his employer might happen at the time to be interested. The employer would, it was hoped, supply the machine or instrument he wished studied, and the student would be enabled with the assistance of the trained staff, and by the use of the experimental facilities of the school, to obtain results of real practical value; which would be the property of the employer of the student in question.

In conclusion, he hoped that something better would be attempted in the future than had been possible in the past. From all he could learn, a large proportion of the money spent on technical education in this country had produced no useful result, and he was afraid the blame for this lay largely with the engineering employers.

BIRMINGHAM LOCAL SECTION.

(Inaugural Meeting of Section, February 27th, 1901.)

The Birmingham Local Section of the Institution of Electrical Engineers held its Inaugural Meeting on Wednesday, the 27th of February, at the University Buildings, Birmingham, the Chairman of the Section, Dr. Oliver Lodge (Chairman), in the Chair.

The CHAIRMAN said the inauguration of the Section was due to the efforts of Mr. Henry Lea and Mr. J. C. Vaudrey. As Principal of the University he was very glad that the Section should meet in the buildings of the University, and he hoped they would always continue to do so. It was the wish of the University and of all its members to keep in touch with all the higher life of the City and surrounding district, and with none more than with the engineers.

Mr. HENRY LEA explained the beginnings of the local organisation. He said that in response to circulars sent out to the members of the Institution in Birmingham and district, including the counties of Warwick, Stafford and Worcester, seventy-nine replies were received expressing approval of the proposed Local Section, and promising to render assistance. That number, exceeding as it did by twenty-nine the minimum required by the parent Institution for the formation of a Local Section, was considered very satisfactory, and the Section was at once created. They were most fortunate in obtaining the consent of Dr. Oliver Lodge to become their first Chairman. He (Mr. Lea) was appointed Vice-Chairman, and the Committee was appointed as follows:—Mr. F. Brown (Walsall), Mr. Alfred Coleman, Mr. Alfred Dickinson, Mr. G. S. Ram, Dr. Sumpner, Professor Threlfall, Mr. Wyld, and Mr. Vaudrey. The Hon. Secretaryship had been taken by Mr. D. K. Morris. They intended to submit the rules for the consideration of members at a subsequent meeting. It was proposed to meet monthly on the Wednesday evenings.

Mr. J. C. VAUDREY said the membership of the Birmingham Section had now increased to 110, so that they would more than hold their own numerically with some of the other Local Sections previously formed. Birmingham and the district were rapidly becoming a very large centre of electrical industries, and the Section was started with a view of bringing more nearly together those interested in electrical and kindred pursuits, so that the interchange of ideas and knowledge might help engineers as a whole.

The CHAIRMAN then delivered his Inaugural Address.

INAUGURAL ADDRESS BY THE CHAIRMAN.

Professor OLIVER LODGE, D.Sc., F.R.S., Member.

The first thing it behoves me to do is what my magnificent friend FitzGerald did on opening the Dublin Section, viz., congratulate the parent Society on its wisdom and enterprise in forming these local branches. And I congratulate them not only on the idea, but on the way they are executing it: on the free constitution they give, and on their system of publishing and utilising papers communicated. A multiplicity of publishing centres is bad for science: the more unified publication can be the better. At the same time, excessive centralisation and lack of stimulus to exertion at local centres is bad, too. If anything, it is the greater evil of the two. But by the present action of the Institution of Electrical Engineers, both evils are avoided. Local ability and energy are stimulated and encouraged, and at the same time the advantage of central publication is secured. I hope that the good example thus set may be followed by other societies. If the experiment succeeds it will be followed. A successful experiment is a splendid thing, for it can be repeated and can develop unimagined advantages.

Next I would thank my good friend the President of the Institution for coming down to give us his support and encouragement at this our inaugural meeting.

Professor Perry is an educational authority and a great educational enthusiast. He is an engineer, but he is also a physicist and a mathematician, and he is a great many things beside those. Catechise his students and you will find that they learn from him not engineering and mathematics alone: they learn much of those, but they learn a good deal about other things as well. They are even guided by him in their miscellaneous reading. I can tell you that things are, or used to be, lively in Perry's class-room. And when he got workmen to come and hear him, men who were familiar with engines and machinery but ignorant of the laws of motion, they were not treated to high and dry principles or to abstract science; but the machine which they knew was taken as the basis, and

fundamental principles were dissected out from it by the hand of a master. Not every one can do that, nor is it equally suitable to all grades and kinds of students; but to the artisan it is suitable, and the work which Perry did at Finsbury had the most admirable results.

Now he is engaged on reform of school education and primary education, and he is full of vigour and originality and plain-spokenness in these things, too. Nor would he be for a moment backward in dealing with University education. If we do not go straight in developing this University on sound lines, you may depend upon it that Perry will let me know.

Well, he has plenty to do where he is, and I recognise in him a man genuinely anxious to serve humanity, full of energy, full of knowledge, full of enthusiasm, and, what is more, full of goodness—one of the kindest-hearted Irishmen of them all.

In the rough-and-tumble of London life, people are so busy they neither give nor take credit for the more human virtues. He has to come down to the provinces to hear his character, and I daresay he is astonished to hear it. But I mean what I say; and I say no more.

The Society has to do with electrical applications—a large subject, if ever there was one. It began as the Society of Telegraph Engineers, and dealt chiefly with cable enterprise; then it took over the telephone, then electric lighting, then transmission of power, then tramcars, and now it is likely to take over nearly all underground locomotion. In time, and in some countries at any rate, it may take over the railways themselves. Nor is it confined to civil engineering. A ship of war is full of electric contrivances; and the Society sent a corps of experts to add to the land forces in South Africa.

There are, indeed, other engineering societies, notably the Civil and the Mechanical, both powerful, well-established organisations; and very kind, hospitable, and helpful has that ancient and distinguished body, the Civil Engineers, been to their younger Cinderella sister, the electrical branch of the profession, whose future is destined perhaps to rival in brilliancy, though by no means ever to eclipse, their own services to humanity.

Concerning applications of science there seems to be a

fallacy still abroad in this country, judging by the tone of some recent presidential addresses and public utterances designed to controvert it. Some misguided persons seem to hold that general education and mathematics are unpractical and useless encumbrances. What they really mean is that if a youth has them and nothing else he is less useful than if he failed to possess these but did possess many other powers and aptitudes. Quite true, if the two are mutually incompatible. But why try and compare two evils and choose the lesser? Why not go for a positive good? Why not advocate all the business virtues and the engineering genius if you can get them, and advocate all the mathematics and physics and acquired learning as well?

Well, if you do, you get John Hopkinson and men like him (not to speak of the living), and that I take it is the type of man you want.

But the objection arises from a suspicion that mathematics is often so badly taught that by the time a man has acquired a great deal of it he is somewhat unfitted for anything else. If that is so it is a grievous fault, and I know that the fault does exist. The training of a pure mathematician is one thing, the training of engineers and physicists is another. No one would be the worse for a common-sense mathematical training, some even of pure mathematicians would be a great deal the better for it; but an engineer must have it or must invent it for himself—no light task.

Well, this reform of mathematical teaching has been taken in hand by several. All of us recognise the need of it: nearly all physicists and engineers, I mean. I realise it strongly. But no one has more vigorously and recently taken up the cudgels and belaboured opponents than our President: so that now the old Mathematical Tory dare hardly raise his head. We only wish he would. He is always being coaxed to put his head out, like Kruger's "tortoise," and then the bludgeon will descend. But he stays in his shell, and perseveringly conducts the patient English youth by roundabout paths over that asinine bridge and other antiquities, the continued school use of which is a monument of modern education folly.

I wish some one would advocate teaching Greek methods of arithmetic as well, for then surely rebellion

would set in; but unfortunately Euclid's arithmetical books were lost.

Euclid himself was splendid. So was his book; for its day and generation, and its purpose as a system of geometrical philosophy, admirable; but like some other good things, it has had its day, and for elementary and popular purposes should cease to be. We are too busy; there is too much to learn nowadays, to leave time for us to cross every river by ascending to its source and walking down the other side. Professional guides along the old river-path still attempt to hide the bridges, because if they were too easily seen their occupation would be gone; but the bridges are there, and sooner or even later schoolboys will be permitted to make use of them and enjoy the country on the other side, without spending all their days in a toilsome and deterrent mode of getting there over a route approved by the ancients.

If there be any workers in engineering or any other branch of technology who affect to despise pure science and say that its pursuit is needless, they are hardly worthy of notice. It must be affectation. Even so might a coal miner affect to despise the sun, on the ground that he did not need it below ground, that he could do his work quite well without it, not realising that it was the sun which put the coal there!

And if any man is so immersed in what I may call black-country undertakings as to forget the smiling face of his mother-earth, let him realise that his health and sustenance are the outcome, not of his useful burrowings and grimy surroundings, but of the sunlit surface and the peaceful agricultural pursuits he has been compelled to abandon, and which at present seem so foreign to him.

So is it with those immersed in practical applications, who forget their indebtedness to and dependence on the past, the present, and the future of pure and undiluted science.

But, on the contrary, it is to be heartily admitted that the enlarged experience and the large scale experiments rendered possible by the wealth of communities who apply science to their own convenience reacts with immense advantage on the pure science itself. The thing is manifest, and needs no enforcing. But those large scale experiments are hardly

like experiments proper, they cannot readily be tampered with (one is rather nervous about interfering with the traffic or the illumination of a district to observe, say, the capacity-rushes in mains); they remind one of astronomical observations rather than of laboratory experiments. The essence of an experiment is that it shall be modified in all sorts of ways, and shall be lived with on terms of familiar intimacy, not that it shall be regarded from a distance through a telescope furnished by inspectors' and workmen's reports, with illustrations drawn from letters of indignant consumers to the public press.

To understand the blaze of a new star and disentangle its meaning with a spectroscope, demands first that the spectroscope shall have been invented and comprehended by laboratory physicists and chemists and mathematicians; let us say by Kirchhoff and Bunsen and Stokes; and, without similiar purely scientific work, the large scale occurrences witnessed in industrial enterprise would not be rightly and readily understood.

Yet it is not to be urged that pure science should really be studied simply and solely for its own sake, apart from the needs of humanity: as the cant phrase used to run a few years ago, "Art for Art's sake."

The pursuit of pure science for its own sake is a good and wholesome formula up to a certain point, because the tendency of unregenerate man has always been opposed to it. The usefulness of scientific applications needs no preaching, but strangely enough there is a great tendency to forget or ignore the scientific foundation on which they rest. And the human mind is so constituted that, as a rule, the necessary powers and aptitudes for both do not go together. The man who can pursue pure science does so best, as a rule, when he is not distracted by considerations of utility; the applier of science, on the other hand, soon gets so immersed in practical details and pecuniary considerations, which are clearly vital, that he has neither leisure nor inclination, nor always the right kind of ability, for advancing the pure science itself. Pure science must always advance into territory which appears for the moment rather useless and barren and aloof from humanity; it must be so, since it is new ground never open to humanity before. Consequently, there is a weird unearthliness about it, which,

to people engaged in the turmoil of business, may feel cold and repellent, if ever they allow themselves to be assisted to breathe its atmosphere for a moment.

But the strange, new, unknown, bracing air has a fierce fascination of its own, akin to that of the lone ice-packs of the Arctic seas, to the healthy and intrepid explorer, or as the mountain-tops are to a member of the Alpine Club. So enticing does the atmosphere of pure science become, to those who frequently breathe it, that to them sometimes it feels the only air worth breathing, and the everyday atmosphere of humanity strikes close and stifling in comparison. Let such men alone, encourage them in their quest, they are not too numerous, and whither they show the way others hereafter will follow.

Moreover, the region which they enter is no limited Arctic circle in reality; it is, as it were, the arctic entrance to another world, whence, if we penetrate further, in pursuit of the pioneers, we shall reach ultimately the temperate zones of work and livelihood and applied science; nor need we doubt but that at some date, as yet far distant, the human race may at length make its way on through these regions too, and attain, even by this apparently arid path, the rich tropical belt of luxurious verdure and bright sunshine, where conflict ceases, and art and enjoyment and emotion and religion begin.

Facts known to few, with effort, are science; but those same facts when known to all, without effort, are æsthetic; they can then be appreciated in a fuller and higher way, can be seen in an altogether new light, so that they become fit subjects for poetry, for music, and for art.

Meanwhile the justification of all pure dry science lies essentially in its ultimately human bearings. If a subject could be proved to be never capable of any human influence, or any relation to humanity, however developed it might become, then its pursuit would be rightly condemned. But such proof can never be given. Again and again have the most unlikely channels developed into fruitful watercourses; we must trust the instinct of our leaders and let them advance unhampered, in faith that where they feel so much enthusiasm, where they seem to see their way so clearly and so well, we, too, in time, or our descendants, shall be able to enter with their aid, and shall realise that

the remote, and at first sight hopelessly inaccessible region is full after all of human interest and of that which contributes to the enrichment of life.

We are in the beginning of a great era in connection with the pure science of electricity. The almost despised and neglected subject of electrostatics, as known to Franklin, is rearing its head again, and is pressing to the front.

The experiment of a charged rod and pith balls is typical of much, perhaps typical of all that goes on in electricity: and how much this means some of us are beginning to guess. We must look to Larmor and FitzGerald to explain to us if they can the nature of an electric charge—that blank, that absolute void, so wisely left by Clerk-Maxwell in his scheme, left also by Helmholtz in his, a void occupied by the isolated brilliant surmise contained in the phrase, "one molecule, or atom, of electricity."

But even before we understand the nature of an electric charge, we shall find that the labours of J. J. Thomson have enriched the science of our times with what appears likely to be a unifying and comprehensive generalisation, such as philosophers of all time have groped after, for which some of them have strongly hoped.

Prof. Perry. Professor J. PERRY (President) proposed a vote of thanks to Dr. Lodge for his address. He thanked the Chairman for his references to himself, observing that, engaged in the crusade in which he was embarked, and subject to much adverse criticism, praise of the kind he had received from Dr. Lodge was of special value. He had got much credit for what he happened to have done with regard to the new educational movement, but the fact was he hit upon the psychologic moment when people's minds were moved by what had happened in the Transvaal, and were very much alive to the necessity for a large change in the education of everybody in the country. All the scientific world was watching to see what Dr. Lodge was going to make of the great problem that had been set before him in the Birmingham University. Dr. Lodge was a leader in science, a man much of whose laboratory work was being carried out on a large scale by engineers.

He deprecated the tendency in the parent Institution to array professors and engineers against one another, and advocated the cultivation of a spirit of mutual helpfulness, as between men whose various endowments must be interdependent if they were to be fully utilised. Referring to the untimely death of Professor Fitzgerald, he said that Professor Fitzgerald had done the most magnificent scientific work, helping every one in their difficulties, perfectly unselfish, a perfect man. On all practical engineering questions he had not only the

laboratory experimenter's point of view, but also that of the practical engineer. He had no hesitation in saying that in Professor Fitzgerald their profession had lost one of its greatest and most beneficent forces. With regard to the prospects of the Local Section of the Institution they were now inaugurating, it was an advantage to the members to be working in Birmingham. Why were things called "Brummagem"? Whether they had in hand a button, a watch, a thimble, a steam engine, or mechanical engineering of any kind, the Birmingham people took the scientific method of going about the manufacture. They were the first people in the world, he believed, to go in for that which everybody was preaching now, the science of manufacture, probably the most important science of engineering at the present time. And the Philistines, who hated science in every form, therefore distinguished all scientific manufacture by the contemptuous expression "Brummagem." Prof. Perry.

Touching upon the stress of international competition, Professor Perry said the danger which Huxley pointed out from the diffusion of education in foreign countries, and the neglect of it in England, was rapidly coming upon us. Could the men of Birmingham not raise their voices to save the nation of which they formed such an important part? Electricity had done great material things, and at second-hand she had done much for the moral good of the world, but it was not electricity, it was the Institution of Electrical Engineers that was going to have the great triumph of the coming century, binding all the best thinkers together in an association for the common good.

Professor THRELFALL seconded the proposition. He expressed his concurrence in the condemnation of the prevalent system of teaching mathematics in public schools, but said he did not endorse the perpetual tilting at their old friend Euclid. It was not so much the study of Euclid, but the setting up of algebra as a sort of puzzle for tripping lads, that was to be reprehended. They had that evening listened to an address which, like all Dr. Lodge's addresses, represented the high-water mark of the state of electrical science of the day. Dr. Lodge was now devoting himself to the development on new lines of a University untrammelled by a past age. They must all wish him success in his work. Professor Threlfall.

Professor PERRY then put the resolution of thanks for the address to the meeting, which was enthusiastically adopted. Prof. Perry.

The CHAIRMAN: As a close personal friend of the late Professor Fitzgerald, who was at the time of his death the Chairman of the Dublin Local Section, the CHAIRMAN, before concluding the meeting, testified to his distinguished services to mankind, as well as to the human and domestic virtues which illumined his life.

NOTICE.

1. The Institution's Library is open to members of all Scientific Bodies, and (on application to the Secretary) to the Public generally.

2. The Library is open (except from the 14th August to the 16th September) daily between the hours of 10.0 a.m. and 6.30 p.m., except on Saturdays, when it closes at 2.0 p.m.

An Index, compiled by the late Librarian, to the first ten volumes of the Journal (years 1872-81), and an Index, compiled under the direction of the late Secretary, to the second ten volumes (years 1882-91), can be had on application to the Secretary, or to Messrs. E. and F. N. Spon, 125, Strand, W.C. Price Two Shillings and Sixpence each.

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JOURNAL

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The Three Hundred and Sixty-Second Ordinary General Meeting of the Institution was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, March 28th, 1901, Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary Meeting held on March 14th were read and confirmed.

The PRESIDENT: The following communication has been received from the Home Secretary:—

"HOME OFFICE, WHITEHALL, S.W.
"*23rd March*, 1901.

"SIR,

"I am commanded by the King to convey to you hereby His Majesty's thanks for the loyal and dutiful resolutions of the members of the Council and local sections of the Institution of Electrical Engineers, on the occasion of the lamented death of Her late Majesty Queen Victoria.

"I am Sir,
"Your obedient Servant,
"(Signed) CHARLES T. RITCHIE.

"The Secretary,
"Institution of Electrical Engineers."

The names of new candidates for election into the Institution were announced, and it was ordered that the list of names should be suspended in the Library.

The following transfers were announced as having been approved by the Council:—

From the class of Associates to that of Members—

Arthur George Seaman.
Philip James Watts.

From the class of Associates to that of Associate Members—

George Dean.
Herbert Buchanan Harvey.
Herbert Francis Hunt.

From the class of Students to that of Associates—

William Richard Colville Barrington.
Edward George Paul Bousfield.
J. F. R. Jacomb-Hood.
Ernest Albert Rosenheim.

Messrs. H. G. Wood and F. H. Howard were appointed scrutineers of the ballot for the election of new Members.

Donations were announced as having been made since the date of the last meeting to the Library and to the Building and Benevolent Funds from:—*The Library:* E. Ackermann, Messrs. Vieweg and Son, Mr. W. L. Madgen, Member; *Building Fund:* Messrs. H. J. Eck, S. Glendenning, A. P. Pyne, W. E. Langdon, James C. Smail; *Benevolent Fund:* Mr. W. R. Rawlings; to whom the thanks of the meeting were duly accorded.

SOME NOTES ON THE ELECTRICAL TRANSMISSION OF POWER IN COAL MINES.

By H. RAVENSHAW.

The object of this paper is to discuss the special features met with in electric power plants in coal mines, and to give a record of difficulties and mishaps which have come directly before the notice of the author during the last ten years.

A great many of these plants are now in use, and are doing good work all over the country, lighting, pumping, haulage, and coal cutting being the principal uses to which electricity has been put.

LIGHTING.

It is usual to employ a separate plant for lighting, as the lamps are required in the pit night and day. A pressure of 220 volts is usually employed for the lighting circuits, and from 300 to 800 volts for the power.

Underground engine-rooms, which are at a considerable distance from the generating station, are often lighted from the power mains with several lamps in series. The light is generally very much appreciated, especially at the shaft bottom, and at landings where there is often a good deal of shunting carried on. Where the mine is dry, simplex steel tubing can be used to great advantage in places where there is not likely to be a fall of roof. There is an immense amount of primitive wiring in use, it being quite usual to run the wires on insulators and for the workmen to bare the two wires and hang a lamp across wherever they want it. This is, of course, only done in the parts of the mine which are not fiery.

Enclosed arc lamps are very suitable for screens and pit heads, as well as for the pit bottom.

Generating Plant.

Very low steam pressures are usually employed at collieries, and, coal being comparatively cheap, the steam engines are often of a primitive pattern. Condensing plants are seldom used.

Old winding engines are very often employed, and have the advantage of being extremely reliable; as a rule, however, they do not govern at all well.

For power the units are usually from 100 to 200 I.H.P. and for lighting 50 I.H.P. In the best plants Corliss and vertical engines, with flywheel governors, are employed. These drive the dynamos with ropes or belts.

Some of the best mines, however, are employing higher steam pressures, and vertical high-speed direct coupled sets.

The most important requirement is absolute reliability, as spare plant is seldom put down, and the machinery often works for at least 16 hours a day.

Generators.

Owing to the fact that non-condensing steam engines are used, there is always a great deal of steam about the surface works of a colliery, and this, combined with the immense amount of fine coal dust, covers everything with a film, which is by no means a good insulator.

For this reason it is not advisable to employ dynamos

which have internal ventilating spaces, and in any case all insulating materials have to be of the very best quality.

The greatest care has to be taken with spare machines and armatures, as these are liable to get very damp.

The author has known armatures which were not suitably insulated to break down one after the other, and this is generally found to occur on damp days in January or February.

Exactly similar machines which were working underground, where everything was very dry, gave no trouble whatever.

The load on the generators is likely to be extremely variable, there being as a rule only two or three motors on the circuit, which may all be stopped at the same time. It is quite usual with haulage for the load to vary from 25 per cent. over-load to open circuit in a very short space of time. It is, therefore, most important that the generators shall run without requiring any attention to the brushes. One man as a rule looks after a fan engine and all the electric light and power engines and dynamos, and if the machinery is suitable he has a very easy time.

SWITCHBOARD.

Owing to the atmosphere being charged with damp coal dust, the switchboard must be thoroughly insulated and must be fire-proof. In a switchboard largely adopted by the author, the slate slabs are thick and rest on a low wall of glazed bricks, the top being supported from the wall of the building by iron brackets. The only woodwork is a strip of teak along the top of the slates, fastening together panels of the same potential. The slates have the edges bevelled, and there is no wood or metal framework.

Owing to the fact that single armoured cables are generally used, any sudden break sets up an enormous tension on the insulation, and it is best to employ massive slow-break switches of the simplest character. A most important instrument for the switchboard is a megohmmeter, arranged to read direct the insulation resistance between either pole and the earth.

A log is kept of the insulation, and any leak put right as soon as possible. Where men's lives depend to a great extent on an absence of leakage, it is of the greatest

importance that everything should be kept in first-rate order.

Cables.

For shaft work there does not seem to be anything better than Callender's Armoured Vulcanised Bitumen Cables, and when these are protected from falling objects and are kept well coated with Stockholm tar, they will last a very long time. The cables are almost always carried down the down-cast shaft, as the fumes and steam in the up-cast shaft are very injurious to the armouring. The cables should be so fixed that they will not be struck by any corves, or other trifles which have a habit of falling down the shaft.

Underground cables are generally suspended from the props which support the roof; they are hung fairly slack and should be suspended by loops of yarn or leather and not nailed up with cleats. If thus supported, in case of a fall of roof, the cables fall to the ground, and are not so likely to be cut through.

Ordinary rubber and lead-covered cables are often used, but a good armoured cable is greatly to be preferred.

All joints should be made in proper joint boxes, as solder cannot be employed, and a single pole switch should be fitted on each conductor wherever there is a junction. Double pole switches should not be used, but single pole coupled externally. These switches should be entirely lined with slate, and made so that there is no possibility of an arc being started to the case.

The switches should be made so that they will break the circuit with certainty in case of a short circuit.

Switch Gear for Motors.

Where the cables enter the underground engine-room, they should be connected to two single pole switches, similar to those mentioned in connection with the junctions.

It is most important that the shunt circuit of the motor should not be broken, as the extremely high tension at breaking causes a vicious spark and puts tremendous stress on the insulation. By far the safest plan is to connect permanently across the shunt coils a non-inductive resistance of about twice the resistance of the fields. The

current used is very small, and the field circuit can be broken with impunity.

The author has known the shunt coils of a motor to be left on and to be broken by switching off at the surface, thus causing an enormous stress on the insulation of the mains. All series coils should also be fitted with a similar resistance. Precautions such as this reduce the flash from the switches, or, in case of a broken cable, to a very great extent.

Motor Starting Switches.

If a good double pole break is arranged where the cables enter the engine-room, a single pole starting-switch can be employed. This is rather important, as the parts of opposite potential are kept well apart. The author has employed liquid switches with a good deal of success; but it must always be remembered that, where they are used for regulating, steam is given off and ventilation must be allowed, so that leakage is not caused by the condensed steam.

In any case, all resistances should be made so that they will carry the full working current, as they are sure to be used some time or other for regulating.

The cones of liquid switches are of either iron or lead, and should be made so that they can be easily examined and replaced.

Where there is gas, all switches must be entirely enclosed.

Motor.

There appears to be a fairly general opinion that there is a great deal of danger from the explosion of gas ignited by the sparking at the brushes, and a number of experiments have been carried out which do not seem to have proved anything one way or the other. Whether this is so or not, it is perfectly obvious that the heat from a burnt-out armature or the arc from a broken circuit would be quite sufficient to ignite gas, and where there is any chance of gas being present it is necessary that the armature and commutator at least, if not the fields, should be enclosed in strong gas-tight cases. All the terminals should be made so that cables cannot be accidentally pulled

out, and the machines should be of such construction that they will pull up at once in case of a bad leak or short circuit. It is well known that a Gramme armature will go on running for some time with a burnt-out coil, all the time doing itself a very great deal of damage and developing a great deal of heat. A drum armature, however, in which the conductors of opposite potential are close together, will stop at once if there is a short circuit in the armature, and if proper fuses are fitted the machine is at once cut out. This is a most important feature in this type of machine, and Gramme armatures should never be used for any underground mining machinery.

Totally enclosed machines are by no means in favour among colliery managers, as they are difficult to keep clean and to inspect, and the general opinion seems to be that an open machine is to be preferred, precautions being taken that the engine-room is kept free from gas.

Enclosed machines are certain to be run some day with the covers loose or entirely off.

It is possible to obtain motors which will not break down and which do not spark at the brushes, and with careful supervision and an organised testing of the insulation from the switchboard in the generating station, there should be no danger from fire or explosion.

PUMPING.

The advantages of electric motors for this work are obvious, and a large number of pumps are in use. Compound motors are generally employed, as they will not run away if the pump loses its water. Owing to the damp places in which they usually work, pump motors are often entirely enclosed, and shunt wound machines under these circumstances are apt to give trouble owing to the resistance of the fields rising as the machine gets hot. This increases the speed and the armature current. The addition of a fair amount of series winding prevents these difficulties from arising.

HAULAGE.

The author cannot quote a single instance in which electric locomotives have been employed in coal mines,

Wire rope haulage appears to be almost entirely employed. With continuous rope haulage the motor usually runs at a constant speed, the rope-pulleys being started and stopped by means of clutches.

With single rope, and main and tail, haulage the electric motor is shown to advantage, the smoothness of starting and complete control over the speed, as well as the ease of reversal, giving an extremely handy hauling engine.

Coal Cutting.

The motors employed for coal cutting are usually series wound, and are subject to extreme variations of load and to very great shocks. They are entirely enclosed, and are consequently liable to get very hot. It is, in fact, difficult to imagine a more trying load.

With these motors it is, of course, imperative that they should be entirely enclosed, both for the protection of the armatures from falling coal, and to keep out the coal dust.

It is most important that effective switches and cut-outs should be fitted at the junction where the motor cables are carried from the main cables, so that, in case of damage to the flexible cables or of burn out in the motor, both poles are quickly cut out.

Generally.

The amount of bad or unsuitable work to be found in colliery installations is very surprising, and it is apparently only due to the strict supervision and high order of intelligence to be found among those in responsible positions in collieries, that there are so few accidents.

With good work electric power transmission is an immense boon, and there should be a very great field for extensions.

As the author has not employed any multiphase motors in mining work, he is not in a position to discuss their use. Many of the points raised, however, will apply to both systems.

* * * * *

As one mishap gives more instruction than many years of steady running, a list is given herewith of a number of accidents and defects which have come directly before

the notice of the author. For obvious reasons the actual localities are not given.

A. Engines.—A stud sheared which fixed a flywheel governor in place. The engine ran away.

B. Dynamos.—Three armatures broke down one after the other, stopping the pit for three days. The first armature broke down. The spare dynamo had not been run for several months, and on starting up burnt out. The spare armature had been kept in a damp place, and broke down at once. All these armatures were only insulated with compressed paper.

C. The brushes for three dynamos cost £40 in one year, and armatures constantly broke down owing to over-heating. The brush-holders were originally few in number, with large carbon blocks. These were changed for a number of holders, each carrying a small block of carbon. After this alteration the machines ran well, and a set of carbons now lasts for many months.

D. A number of instances of short circuits have occurred, owing to the ventilating spaces in the armature becoming filled with coal dust. The armatures often broke down after they had been standing for some time. The coal dust seems to absorb moisture.

E. Switchboard.—An arc was started at 600 volts between two contacts about 1½ inches apart at opposite potentials on a switch connected to a megohmmeter. The base of the switch was ebonite, and the leak was due to a fine layer of damp coal dust.

F. In another case a voltmeter was entirely burnt out, evidently from the same cause.

G. While there was a heavy earth on the mains an arc was started between a switch on the engine-room switchboard, and part of the metal framework supporting the slate. This was evidently due to coal dust.

H. Cables.—Two armoured bitumen cables were laid in a wooden trough, which was close to a leaking steam-pipe. Both cables went to earth within a few hours of each other. The trough has since been filled with bitumen, and no further trouble has occurred.

I. A nail fastening up a cleat had evidently been driven through an armoured cable, passing through the insulation but not touching the conductor. This finally came in

contact with the conductor, and, as there was a bad leak but not a dead earth on the other pole, an arc was set up and a very serious fire only prevented by the fact that the assistant manager was close by, and telephoned to the engine-man on the surface to shut down.

J. A common twin cable was carried down a shaft for lighting a mine. 60 volts were lost in this cable, the volts at the surface being 110, and in the mine 45 to 50.

K. A runaway train of tubs cut through one of the cables. The accident happened close to a box containing a double pole branch switch. The drag on the cables broke the marble bases of the switch into several pieces, and an arc was started to the iron-case.

A number of cases have occurred where runaway trains have cut the armoured cables clean through.

L. Motor switches.—Owing to there being no stop inside the switch, and the handle being put on the wrong way, a double pole switch was carried back too far and a short circuit effected between opposite poles.

M. A main regulating switch was not marked, and was arranged to switch off left-handed instead of right-handed. An accident occurred to the gear, and the attendant, instead of switching off, switched on to full speed.

N. A double pole enclosed switch was fitted with a fibre arm. The insulation of the fibre broke down and caused a short circuit.

O. A single pole enclosed switch had a cast-iron arm supporting the moving contacts. The arm broke in switching on, but the contacts remained in position. It was therefore impossible to switch off the current, as there was no double pole switch fitted.

P. A gas-tight cover to a liquid switch was fastened by cramps binding the porcelain jar very tightly. The jar cracked when it got hot, and caused a partial earth owing to leakage of the solution.

Q. Owing to insufficient room being allowed for a liquid switch gear, the steam from the solution caused an arc to be started between opposite poles on several occasions.

R. A double pole switch in the shunt circuit of a compound motor worked perfectly well on the surface when tested with its own motor. On being erected underground, at the end of several miles of armoured cable, the length of

break was not sufficient, and an arc carried on between the contacts.

S. *Motors.*—In several cases a Gramme armature has gone on running with a short circuit in the armature, burning the armature to a cinder.

T. No record has been found of a drum armature running on with a short circuit. Several cases have occurred in which the armatures have pulled up at once from a short circuit, the damage to the coils being very small.

U. A cable was brought from the magnets of a large shunt motor to a switch in another part of the engine-room. This cable was loosely run, and was accidentally pulled out of the connection. A tremendous flash was the result, the commutator was badly damaged, and the fuses on the surface blown.

V. The shunt circuit of a compound motor was broken, and the motor ran away.

W. After some repairs the series coils of a compound motor were connected up the wrong way. The machine gave a great deal of trouble, and it was some time before the mistake was found out.

X. A shunt motor driving a pump was driven by a shunt dynamo through a long line. The motor was enclosed, and the fields got very hot. The field of the motor being weakened, the current increased, and it was found to be impossible to run the plant for more than two or three hours at a time.

ELECTRICAL MINER'S SAFETY LAMPS.

By SYDNEY F. WALKER, Member.

Ever since the historic occasion when Mr. Swan presented his incandescent lamp to the Society of Telegraph Engineers, it has been the dream of electrical and of mining engineers to adapt the lamp for use in mines, especially those in which carburetted hydrogen gases are given off in working of the coal.

The dream has been realised to a certain extent. In nearly every coal-mine of any size the whole of the surface arrangements, together with the shaft bottoms, the main roads for a certain distance from the shaft bottoms, and the

underground engine-houses and other important points, have long been illuminated with incandescent lamps of various powers, much to their advantage; but up to the present very little has been done in the way of the adoption of the incandescent lamp in the most important positions in coal-mines, viz., at the face of the coal.

Mr. Swan himself was very early in the field with a proposal to use lamps at the face of the coal, taking their supply of current from the regular lighting service, and some attempt was made to introduce it in that form; but mining engineers felt that the possibility of a spark passing between the broken ends of a severed cable was too serious to be entertained, and no attempt has since been made to introduce that method, except that in some cases, where electric pumps are working at or near the face, incandescent lamps are in use, taking their current from the power supply service.

And so the solution of the problem involved in the use of electric lamps in places where inflammable gas might be met with, resolved itself into the provision of a portable lamp of such power, and under such conditions, that it should be impossible for the lamp or any of its accessories to fire an inflammable gaseous mixture.

A great many inventors, headed again by Mr. Swan, have made repeated attempts to solve the problem, but up to the present only one lamp is in practical use in the collieries of the United Kingdom, the invention of a Belgian named Sussman, and only a very limited number of these are actually in operation in this country, and their use is confined to two or three collieries in the county of Durham.

On the Continent of Europe a good deal more has been done in the matter, but the writer believes that even there it is only the Sussman lamp that is in use.

The problem itself, like a good many more that electrical engineers have to deal with, looks remarkably simple until you come to endeavour to solve it, and then it is seen what a really serious problem it is.

The present miner's lamp, a few samples of which are shown, consists of a short brass cylinder, about 3 inches in diameter, forming the oil-well, with its wick, and a wire pricker to stir it up when it is dull, surmounted

by a stout glass cylinder and by an arrangement of three wire gauzes, fitting one inside the other, the whole of the gauzes being protected from injury by an iron bonnet. The gauzes and glass are carried by a brass framework into which the cylindrical oil-well screws, and the whole lamp is carried by an iron hook attached to the top of the bonnet, the hook being large enough to hitch into the collier's belt when he is walking, attending to trams, &c.

The lamp, made in brass, weighs from $2\frac{1}{2}$ lbs. to $3\frac{1}{2}$ lbs.; made in aluminium it weighs from $1\frac{3}{4}$ lbs. to $2\frac{1}{2}$ lbs.

It furnishes a light, when first lighted, of from $\frac{1}{4}$ candle to $\frac{2}{3}$ candle, each for 12 hours if required.

It costs, in brass, from 5s. 4d. to 15s.—the 15s. is a special pattern.

It costs to maintain from 2d. to 3d. per lamp per week, including oil, wick, glasses, cleaning, and repairs of all kinds.

A glance at these figures will show one reason why the problem to be solved is such a difficult one. The electric lamp which is to take the place of a miner's lamp at present in use, must either fill all these conditions equally with the present lamp, and provide other advantages in addition, or the advantages which it possesses must be such as to compensate for any shortcomings, in any respect, in which it is inferior to the existing lamp.

In order to understand how real the difficulties are, it may be as well briefly to examine the conditions under which the miner has to use his lamp, and afterwards to see how near inventors have been able to get to the existing conditions by means of electricity.

In the first place the weight forms one of the most difficult parts of the problem. The collier cannot afford to have the weight any greater. As it is, he resists to the uttermost the introduction of safety lamps into a mine in which naked lamps have been previously employed, notwithstanding that the change is always brought about by the strongest action of H.M. Inspectors of Mines, and always with the view of decreasing the loss of life among the colliers themselves; and he resists partly because the light given is less with the safety lamp than with the candle which he has used before, and partly because of the weight of the lamp itself, and the restrictions which its use imposes upon him.

Walking upon a road in a colliery, even when it is of the very best, and one of the main roads, is very much more tiring than walking on the ordinary high road on the surface. The best of roads in a colliery may be compared to a road composed of loose sand, with rails laid somewhat irregularly, and with holes and various obstructions at irregular intervals. But this is one of the best roads. Often the road the collier has to travel, to and from his work, is so cramped, part of it at any rate, that he cannot stand upright. Often he has to go to his working-place by a sort of grasshopper motion. Often again, either going or coming, he has to mount inclines so steep that the writer, in going down them, has found it necessary to sit down on the rails and work his way down very cautiously; and in many instances also the collier has to go a long distance to and from his work after he reaches the shaft bottom—a mile is a comparatively short distance if the colliery is a large one.

Under all these circumstances it is not surprising if the collier objects, somewhat forcibly, to any addition to the weight he has to carry. And so impressed are mining engineers with the absolute necessity of not giving the colliers any additional weight to carry, that when Mr. Swan presented his first lamp to the North of England Institute, one of the leading members, who was very favourably impressed with the lamp, proposed that the lamps should be taken to the face on coal trams.

Mr. Swan's first lamp, the first that was introduced in this country, weighed 8 lbs., his second weighed $5\frac{3}{4}$ lbs. Mr. Pitkin's, which had a good trial in a large number of mines, weighed 8 lbs. The Sussman, in use at South Hetton colliery, in the county of Durham, at the present time, weighs 4 lbs.; the writer's weighed, when charged, $3\frac{1}{2}$ lbs.

The first cost, and the working cost, of the miner's lamp would be, in the writer's opinion, prohibitive if competition with electric lamps is to be only on those lines, except with the most expensive of the whole series of ordinary miner's lamps, whose cost again is being constantly reduced.

To show also that the matter of the working cost is not a bugbear, a case came under the writer's notice in which one of the companies manufacturing the ordinary miner's lamps, the one which is making the most advanced form of

lamp for the purpose, had contracted with a firm of colliery owners to maintain all the lamps at several collieries, and to provide the lamps themselves on a hire system, for 2d. per lamp per week, inclusive of everything; but the colliery owners, acting upon the advice of their manager, as soon as it was seen that the lamp was really satisfactory, purchased them all, because, as the manager told the writer, they could maintain the lamps cheaper than the figure given, after allowing for interest on the cost.

But these are not the only difficulties before we come to those which are purely electrical.

The source of light, whether it be a candle or a safety-lamp, performs a double office for the collier. It furnishes light, and also indicates the presence of gas.

In the formation of the coal-beds, during the thousands of years that have elapsed since the vegetation of which the coal-beds are formed died, large quantities of carburetted hydrogen gas have been evolved, in the process of the decay and subsequent action which goes on, and in the deeper coal measures the gas is still held in the pores of the coal, just as water is held in the pores of a sponge, coming away, more or less freely, as the coal is worked, in the operation of cutting it away from its bed. Where gas is present, as with all steam coals, it is coming away, more or less constantly, all the time, and is quickly diluted by the strong current of air with which the working coal-faces are swept in modern mines; but in some mines, and in most steam-coal collieries at some time, heavy rushes of gas take place, owing to the sudden liberation of a volume of gas which has been imprisoned in the strata, and in those cases the ventilating current is not always strong enough to dilute the gas sufficiently quickly, and it becomes important that the colliers who are working there should retire, and that for that purpose they should have timely warning, not only for the safety of the mine, but for their own protection from the inhalation of the gas itself; and no warning is given by smell, as with our domestic illuminating gas.

Carburetted hydrogen gas passes through three stages, according to the quantity of atmospheric air that is mixed with it, and in two of its stages it is dangerous to the miner.

When pure, undiluted with atmospheric air, and up to a

point of dilution of four volumes of air to one of the gas, it will not ignite, and consequently cannot explode, because the necessary quantity of oxygen gas is not present.

When it is diluted with eight volumes of air of atmospheric air, and up to a dilution of thirty volumes, it is inflammable and explosive. The most explosive mixture consists of one volume of gas to 9·4 volumes of air. After this the mixture becomes less and less dangerous till at thirty volumes it is again neither inflammable nor explosive, because the mixture is damped by the large quantity of nitrogen gas present.

The first and second stages are dangerous to the working collier, because he may be breathing the gas, and the second stage on account of the liability to ignition.

But other gases are also present in coal-mines, viz., the deadly carbonic acid gas (CO_2) and the even more deadly carbonic oxide (CO).

These gases are often present in old working-places which have been abandoned for a time, and they are always present after an explosion, and are the cause of the great danger incurred by the exploring parties who always go into the mine after an explosion to rescue any men that may be still alive.

Both the ordinary safety-lamp and the naked candle denote the presence of carburetted hydrogen gas by an elongation of the flame on the lamp, and of carbonic acid gas by the extinction of the flame. Carbonic oxide gas, which is even more deadly than carbonic acid gas, and sulphuretted hydrogen gas, which is also found in small quantities in coal-mines, are not indicated by the miner's lamp at present in use. Mr. Rosenthal, the inventor of the gas-testing apparatus which the Sussman Company are adding to their lamp, states that his apparatus will denote the presence of any kind of gas; but the writer believes that he has not succeeded in distinguishing between the different gases which may be present, with his apparatus.

Notwithstanding the above formidable list of difficulties in front of the inventor, the successful lamp has such enormous advantages that the writer believes that when once a lamp shall have thoroughly established itself it will be universally adopted, in spite of additional first and working cost. In the writer's experience, extending now over a period of

twenty-five years, he has found, as he expects most members of the Institution have also, that there are successive stages in the history of every successful invention. The first may be termed the laboratory stage, in which the possibility of the thing is demonstrated, but in very crude form. The second is the stage in which the apparatus is in a practical form, but is expensive, both to manufacture and to maintain, and in which it is also usually uncertain in operation. In this stage, notwithstanding the expense and the uncertainty, there are always a limited number of cases in which it is economical, owing to special conditions; and the experience gained in this stage leads to the third stage, in which the apparatus continues to be more expensive to manufacture and maintain than the apparatus which it is to displace, but in which its great convenience brings it within the economical reach of a larger and larger circle of users; and this leads up, in the course of time, to the fourth stage, in which not only is the electrical apparatus more convenient, but it is also more economical in first and working costs.

The electric miner's safety lamp is in the second stage at present.

The advantages which an electric portable miner's lamp possesses, supposing it to be a reliable apparatus, are:—

1. Complete freedom from the risk of an explosion from any carelessness or wilfulness of the working collier.

At present, the colliery in which gas is given off in such quantity as to form an explosive mixture with the atmospheric air is completely at the mercy of the ignorant or careless collier. A blow from his pick may cause a crack in the glass, which will admit the gaseous mixture if present; the sudden tapping of a reservoir of gas may, by the passage of a continuous stream of an explosive mixture through the lamp, raise it to the temperature at which it will ignite the mixture; and the collier himself, when working at the face of the coal, is often tempted to open his lamp when it has accidentally been extinguished, because, to relight it at the lamp station provided for the purpose, he will have to travel some distance towards the shaft bottom, and lose the time that he would be cutting coal.

Many arrangements have been made by different inventors to prevent the collier from opening his lamp, the most

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Many arrangements have been made by different inventors to prevent the collier from opening his lamp, the most

successful of which have called in the aid of electricity; but the writer is informed by practical mining managers that even the most ingenious of these can be opened, if the collier puts his mind into the matter.

2. The second advantage to be obtained from the use of an electric safety lamp is a lessening of the accidents which are so frequent in mines from falls of roof and from accidents due to the machinery that is used for haulage and other purposes.

The ordinary miner's lamp not only gives a poor light, compared with that given by the portable electric lamps which have been tried in collieries, but it is also extremely sensitive. It must not be held much out of the vertical, and it must not be jerked suddenly, or it will be extinguished. The writer, when underground a few weeks since, was climbing over a tram in going to the face, when his lamp accidentally bumped against the tram and immediately went out. Working colliers are, of course, well acquainted with this failing, and are very skilful in keeping their lamps alight, but notwithstanding this, the extinctions of lamps during the working day are many.

The matter affects the number of accidents from the following: As is well known, the coal-beds lie at great depths beneath the surface, some as much as 900 yards, and the roofs of the roads and working-places have to bear the weight of the superincumbent strata, and in addition there is always going on what is known as squeeze—the sides of the roads are forced inwards, and the floor is forced upwards.

All this is provided for by systematic timbering. Props and beams are placed in all positions where it is thought to be necessary, certain officials of the colliery going round periodically to examine the roof, etc., and to see that all is safe. It will easily be understood that, with a light not good at its best, and one which it is necessary to hold in a vertical position, in which position the light itself is some distance from the object to be examined, say the roof, or a timber which may show signs of giving out, the examination is never so effective as it would be if a lamp was in use, such as the portable electric lamp, which could be held in any position and placed as close as required to the object, and which furnished a better and a clearer light in addition.

This applies also to the operation of fixing timber in the mine, and replacing it as required. The operation of fixing timber is one requiring considerable skill. In most mining districts it forms a prominent feature in any sports that are held; the arrangement of the two upright timbers with reference to the timber which forms the beam, and which the two uprights are to support, requires considerable skill and practice. It need hardly be pointed out that, where these operations have to be carried out in the mine, the use of a lamp which can be held close to the work, and in any position, is of immense value, and must lead to the saving of many lives, it being a well-known fact that, while an explosion sometimes sweeps away several hundred lives in a few minutes, there is a constant dribble of lives going on, due to falls of roof and accidents with machinery, which a lamp of the kind mentioned should at least reduce.

The loss of life and limb from accidents in coal-mines for the last year for which a return has been made are as follows:—

The total number of deaths from explosions of gas, coal dust, &c., in mines in the year 1899 was 54, and from falls of grounds 456. There were 23 accidents from explosions of gas or coal dust, and 443 from falls. Also, there were 13 fatal accidents in coal mines due to the use of naked lights, and 116 non-fatal accidents, leading to the loss of 36 lives, and the injury of 165 persons besides. Again, of the accidents from the use of naked lights, one was due to a collier illegally opening his lamp, and two, leading to three deaths, to lamps being injured while in use. These figures appear to the writer to be very striking.

Since the passage of the Workmen's Compensation Act, each life lost in a coal mine costs the colliery owner from £120 upwards, while each non-fatal accident to a man costs from £60 upwards.[1]

From these causes the writer is of opinion that colliery owners will find it to their advantage to adopt a practical electric safety lamp, even if it costs considerably more to purchase, and to maintain, than the present oil lamp.

The problem, therefore, resolves itself into the provision

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of an incandescent lamp, giving more light than the existing lamp does, attached to a source of electric energy capable of furnishing it with current for twelve hours, eight of which should be such that the light given by the lamp is the best that it is capable of giving, and of doing this at a cost as to manufacture and as to maintenance that shall not be too large a multiple of those of the existing apparatus, and with the reasonable hope that with increased use and increased knowledge the cost may be brought down to and below that of the existing lamp.

There are evidently two methods of attacking the problem involved in the provision of the necessary supply of electrical energy, both of which present considerable difficulties, mainly from the fact that both size and weight are so limited, viz., by means of either primary or secondary batteries.

The only lamp at present in use in this country, the Sussman, is provided with energy by means of a secondary battery, as also were the lamps of Mr. Swan, Mr. Pitkin, and that known as the Bristol, those worked out by Mr. Niblett —all of which had a certain measure of success.

The lamp worked out by the writer, which he was unable to place on the market for financial reasons, has a primary battery, as also had that of Mr. Schanschieff, Mr. Maquay, and others.

The light given by the early lamps, those of Mr. Swan, Mr. Pitkin, and others, measured from 2 c.p. up to 4 c.p., or thereabouts. The light given by the lamps in use on the Continent varies from 1 c.p. up to 8 c.p., or thereabouts. But the English practice, as far as it has gone up to the present, has settled down to a standard of 1 c.p.

Difficulties Common to both Primary and Secondary Battery Lamps.

The difficulties which are common to both forms of lamp lie in :—

1. The incandescent lamp itself.
2. The case which is used to hold the battery.
3. The connections between the lamp and the cells.
4. The prevention of the escape of the liquids used in the battery.

Practice has for the present decreed that two cells, whether primary or secondary, shall be employed.[1]

1. The incandescent lamp itself presents a very considerable portion of the whole difficulty. While lamp makers are able to manufacture lamps of comparatively low candle-power at the high voltages of 230 to 250 volts, they are unable to construct lamps of 1 c.p. or 2 c.p. at voltages below 3½ volts, and those have only recently been made, and are not always as satisfactory as one could wish. One important reason for this difficulty is the fact that, when low candle-power, low voltage lamps are in question, thermal conductivity plays a very important part in the matter.

The filament generating heat and light is necessarily extremely short, and it has also necessarily, according to our present manufacture, connected to its ends two platinum wires, which are in turn connected to two copper wires; hence it follows that a large proportion of the heat generated in the filament is carried off as heat by the terminal wires, and is not available for furnishing light.

When the writer returned to the problem about five years ago, he sent all over the civilised world for lamps which, according to the advertisers, should have given him all that he wanted; but he was obliged to come back to English makers, and to the Edison-Swan Company in particular, before he was able to obtain anything at all near what he wanted. He understands that the inventors of other portable lamps have met with similar difficulties. Lately he has seen some lamps of American manufacture which he believes are nearer to what he wanted, though he has not yet had an opportunity of testing them. His first idea, which the writer believes will be realised when lamp makers turn their attention seriously to the problem, was to have had a single cell of only one volt pressure, as will be explained later, but that he found quite out of the question, as no lamp manufacturer would even consider the possibility of making them, and he was gradually driven to the same point as other inventors, viz., to the 3½ to 4 volt lamp, as the best that could be done for the present.

2. The case which is used to hold the battery, whether

[1] In the case of the Doe lamp, which is described in the paper, four cells are employed, as the E.M.F. of the individual cell is lower than that of the lead, —lead oxide secondary cell.

primary or secondary, has always been a serious stumbling-block to inventors.

The cells must necessarily be held in vessels of insulating material, in the first instance; but all insulating materials are brittle, and many of them bulky and awkward to manipulate, in the small space available; vulcanite, the most suitable in other respects, being the most brittle, and being also very expensive.

Mr. Swan solved the problem in some of his lamps, by using gutta-percha for the cells, and placing the nest of cells in a strong cylinder of hard wood. Unfortunately the gutta-percha softened when in use, owing, the writer understands, to the sulphuric acid which was spilt, generating heat in the well-known manner by attacking the wood cylinder.

Many inventors left the matter practically to take care of itself, providing an outer case of vulcanite and letting it take its chance.

The writer, in his first attack on the problem in 1884, placed his cells, which were of carbon, coated with an insulating compound, in a vessel of copper, coated on the inside with an insulating compound, but the compound and the copper were quickly attacked by the acid which was spilled inside the case each time the battery was recharged.

The Sussman Company use vulcanite cells held in a thin steel case, and in his latest lamp the writer used vulcanite cells held in a case of aluminium, and so far he understands that both the Sussman Company's arrangement and his own have answered, though his own has not had the advantage of an extended trial.

3. The arrangement of the connections between the cells and between them and the lamp, and the switch when there is one, is also a difficult matter. It is not so serious in the secondary batteries as in the primary battery, because with the former it is not necessary to break the connections each time the lamp is used, as it is with the primary battery. On the other hand, with the secondary battery the connections are apt to be overlooked, not being necessarily attended to at each charge; and with both forms there is always the trouble that the liquid, which always contains acids of some kind, will creep to the connecting wires and eat them in two, assisted by the current of the battery itself.

With the primary battery also there is considerable difficulty in arranging that the connections shall be quickly and surely made. It must be remembered that in some of the large collieries as many as a thousand lamps may be in use at the same time, and have to be got ready for the workmen in a certain time, so that any arrangement which involves the occupation of a long time in making connections to each individual lamp will put the lamp out of the running from that cause alone.

4. The prevention of the escape of the liquids used in the battery, whether primary or secondary, is also a matter of considerable difficulty.

If the lamp was always carried in the vertical position, and the collier always travelled at a slow pace, this would be a simple matter; but the collier travels at a fair pace underground, even with all that he has to contend against, and this fact alone causes the liquids in the vessels of which the battery is formed to rise on one side; added to which, one of the great beauties of the electric lamp is to be the possibility of using it in any position. And this is not all, unfortunately. In the working of both forms of battery, as is well known, gases are given off, which also tend to drive the liquids out of the vessels by any opening which presents itself, and severely strains any arrangement made for keeping them in. The escape of the liquid in either battery, it need hardly be mentioned, is fatal.

Difficulties Peculiar to the Secondary Battery Form of Lamp.

The difficulties peculiar to the secondary form of lamp are:—

1. The uncertainty of the life of the battery itself.
2. The fact that so many hours are required for recharging.
3. The uncertainty as to whether a lamp is actually charged when it is sent down the pit, or not.

1. The first difficulty is well known to electrical engineers who have had anything to do with secondary batteries.

As far as the writer's experience has gone, if you have plenty of room for a secondary battery, so that the plates can be kept well apart, and have a space below the bottom

of the plates into which any chippings from the active material can fall clear of the plates, and the battery itself can be kept fairly free from motion, the secondary battery works well, and has a long life; but when you are confined as to space, so that any chippings fall between the plates, and may cause short circuits, and when in addition you subject the battery to motion so that the active material tends to work loose under the operation of the motion and the pressure of the gases formed, the battery has a somewhat short life; and these are the conditions under which the battery has to work in the miner's lamp. It is only fair to say, however, that secondary batteries are being improved in this respect.

2. The fact that the battery requires ten hours to recharge is, of course, not so much against it when a large number of lamps are in use together, and when the whole thing is established on a proper system, but it is rather a drawback in the early stages of its introduction.

3. The uncertainty as to whether a lamp will run its full shift is a very serious matter indeed, and it follows from the same cause as that mentioned in 1, viz., that the active material has a constant tendency to chip off during the use of the lamp, and to drop between the plates and short-circuit one of the cells, with the result that the lamp is extinguished.

The large number of connections necessary for charging a large number of batteries is also a somewhat serious matter at a colliery, and the uncertainty as to how long a lamp will burn may be accentuated if, as is the usual practice, the lamps are charged several in series.

Difficulties Peculiar to the Primary Form of Battery Lamp.

These are :—

1. The difficulty of making a single-fluid primary battery which shall furnish the necessary energy for the lamp for the time required, within the space and weight named.
2. The provision of this electrical energy at a cost that will compare with that of the existing oil lamps.
3. The arrangement of chemicals, zincs, etc., so that the lamps can be charged quickly, and that the

waste chemicals shall not be a nuisance to the colliery.

1. The difficulty of providing the requisite amount of energy within the space and weight named is well known. Primary batteries, though the conditions of working are not the same, require very much the same arrangements for successful work as secondary batteries. That is to say, if you can have plenty of liquid for the secondary salts to be dissolved in, which means plenty of space and weight, and if you can separate the liquids which surround the positive and negative elements, and if you can arrange for the gases which are formed in the working of the battery to come away freely into the surrounding atmosphere, you have a chance of getting a primary battery to give you a fairly constant current; but you have none of these conditions present with the battery which is to work the miner's lamp.

A porous cell would be absolutely prohibitive, as it would so complicate the arrangements for making the connections, renewing the zincs, and closing the vessels containing the cells; and it is doubtful if the porous cell would behave as an efficient separator when subject to the swinging motion that the lamp receives under ordinary circumstances, when the miner is going to his work or when used by hauliers.

Also, in the working of every primary battery, the salt of zinc which is formed upon its surface must be dissolved off, or the usual opposing E.M.F. known as polarisation is set up.

Further, apart from the fact that the hydrogen gas which is liberated in the working of the battery, as well as any metallic salts, require the presence of a certain quantity of material that will deliver up its oxygen in order to get rid of polarisation, the secondary salts which are formed require also a certain quantity of liquid that will dissolve them, or they will also form resistance and opposing E.M.F.s, which will quickly decrease the working current from the battery. And it is a most difficult thing to put all these, in one liquid, within the space and weight that are permissible, and to provide as well for the solution of the gases which are formed in the working of the battery.

2. The provision of the necessary energy to furnish the

required candle-power at a price which will compare with the present cost of doing the same work is perhaps the hardest problem of all.

When the problem is attacked in a practical manner, it is found that in order to obtain the necessary quantity of energy within the space and weight allowable, it is absolutely necessary to employ the strongest acids on the market; and again one of the most powerful, nitric acid, cannot be used on account of the fumes which are formed by its decomposition in working of the battery. And practically the problem resolves itself into the employment of one of the salts of chromium, which are unfortunately very expensive as at present made. The zinc used in the battery is not a serious item, and all ends of zincs unused can be worked up again.

Several inventors have proposed the recovery of the used-up liquor and the working up of the materials, but one great difficulty has always stood in the way, viz., that of collection of the used-up material. A substance may be of a certain value at a chemical works, but if it costs more than that value to deliver it there, its actual value becomes a minus quantity. Nevertheless, in the writer's opinion, it is in this direction that primary battery inventors of electric miner's lamps must work, and he believes that, with proper organisation, any difficulties met with would be overcome. The problem involved is to a large extent similar to that involved in dealing with a large number of secondary battery lamps: organisation is what is required.

3. The third item in this connection is by no means one to be despised. Where there are, say, a thousand lamps to be supplied with liquid every day, and each lamp takes one pint, or thereabouts, the quantity of liquid to be stored at the colliery, or to be prepared each day, is a serious matter, as is also the provision of arrangements for quickly filling the cells each time they come for charge, and quickly emptying them, together with some necessary provision for dealing with the old material, and the testing and cleaning of the different parts in addition. Again, however, in the writer's opinion, the whole of this is a matter for organisation.

And now as to how far the requirements of the situation have been met.

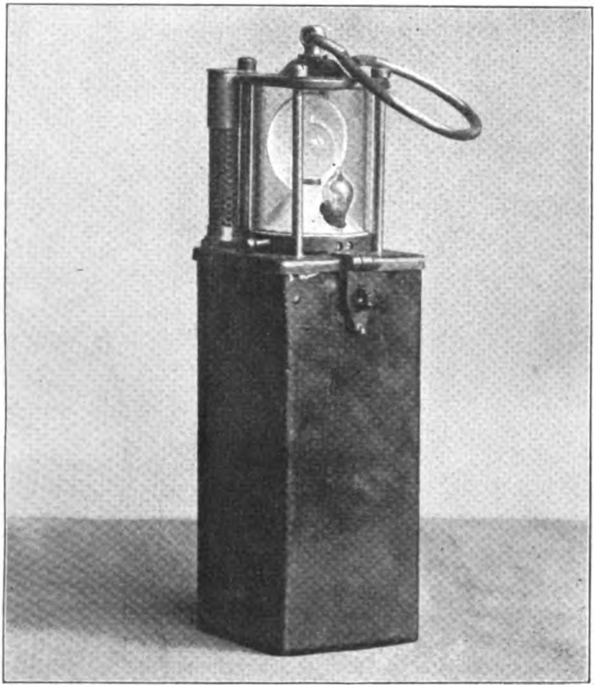

FIG. 1.—The Sussmann Electric Miner's Lamp, with gas detector attached. The small incandescent lamp in front forms the detector, brought into circuit by a mercury column shown inside the metal gauze on the left of the lamp.

Secondary Battery Lamps.

Secondary battery lamps are represented by those of Mr. Swan, Mr. Pitkin, the lamp known as the Bristol, and the Sussmann, the Headland, as well as those of Mr. Niblett and other experimenters. The Sussmann lamp is shown in Fig. 1, and the Headland lamp in Fig. 2.

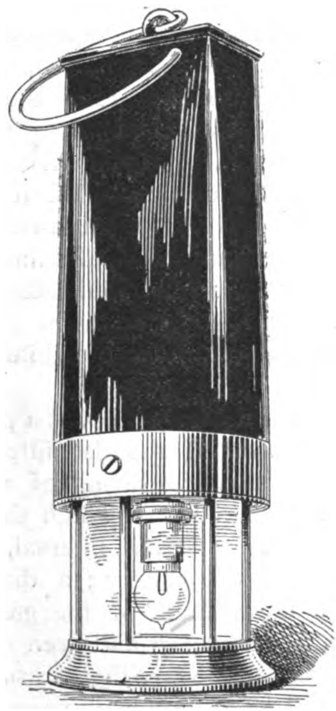

Fig. 2.—Headland Electric Miner's Lamp. The storage battery is inside the bonnet, in the upper part of the lamp.

Mr. Swan's first lamp, which was brought before the North of England Mining Institute in December, 1885, contained seven separate vulcanite cells, fixed inside a vulcanite cylinder with a vulcanite cover. The outer vulcanite cylinder measured $4\frac{1}{2}$ inches in diameter, by $7\frac{1}{2}$ inches high. Each vulcanite cell contained a grooved lead cylinder, the grooves being packed with spongy lead, and a lead wire in the centre coated with peroxide of lead and wrapped with a cloth; dilute sulphuric acid, as usual, was the electrolyte between the elements. The lamp was fixed on

the side of the outer cylinder, protected with a glass bull's-eye, and backed by a piece of white cartridge paper. The lamp gave a light of 2½ candles, gradually falling to two candles; it weighed 8 lbs.

So far as the writer is aware, this lamp never came into practical use.

Mr. Swan's lamp of 1886 was made in two sizes, with two and four cells respectively. The body of the lamp consisted of a block of hard wood, with two or four ebonite cylinders embedded in cylindrical holes provided for them in the block. The terminals were at the bottom of the lamp, and a gas tester was attached to it. It weighs 5¾ lbs.

Mr. Swan's lamp of 1887, the writer believes, the last which Mr. Swan brought out, consisted of four cylindrical cells, formed of one casting of gutta-percha, the whole embedded in a block of hard wood, and the outer case fitted with a strong iron cover, with a handle attached, and a lock. The incandescent lamp was placed on the side, with a bull's-eye to protect it, and a disc of white cartridge paper for a reflector.

It furnished a current of 0·5 amp. at a pressure of eight volts, and weighed 8 lbs. It was also fitted with a detachable gas-testing apparatus, consisting of a platinum wire within a combustion chamber to which the atmosphere to be tested was admitted for a short interval, and the current then turned on from the battery; a dial registered the amount by which the volume of the gases present was diminished, when the firedamp had been consumed by the heated platinum wire, this being the measure, properly proportioned in the dial, of the firedamp present.

Some three thousand of these lamps were ordered for a colliery in South Wales, and six hundred were actually supplied and put to work, but their use was abandoned on account of the fact already mentioned, that the gutta-percha softened owing to the heat developed by the action of the sulphuric acid on the wood.

When Professor Silvanus Thompson gave his lecture on Electricity in Mining to working men, at the British Association meeting at Cardiff, in 1892, he exhibited some of Mr. Swan's then latest pattern lamps, which were, the writer believes, similar to the last described, except that a very pretty and, it appeared to the writer, a very practical

form of switch had been added, consisting of a bent glass tube, inside the wood block, with two platinum wires, inside the tube, representing the two sides of the switch, with a mercury globule which, by canting the lamp, could be caused to close the circuit, or open it as required.

In the writer's opinion, it was a great pity that other business prevented Mr. Swan from attacking the problem again.

Mr. Pitkin's lamp consisted of four rectangular vulcanite cells, each with a pair of lead plates, properly formed, the four being fixed in a polished wood box. The box had a wooden cover, which either slid into a groove or was screwed on. The incandescent lamp was carried on one end of the wooden box, in the focus of a reflector, and protected by a strong glass.

It also had a switch and an adjustable resistance, a very pretty arrangement, but one the writer feared at the time would be found too delicate for colliery work. It consisted of a rheostat formed by coiling a resistance wire round another wire, and forming the two into a circle, over which a contact-piece, fitted with a thumb-piece, moved.

The lamp was supported by a leather handle, which was nailed to each end of the wooden box.

The lamp weighed about 8 lbs., and gave a light in one direction of about four candles.

It was tried at a number of collieries: in one case that the writer knows of, the manager going so far as to give two colliers, working at the face, a lamp between them, so that the question of weight should not be prohibitive.

As far as the writer is aware, no lamps of this kind are in use at present in collieries in the United Kingdom, and he believes that they succumbed to the three causes which he has named, viz.: The inherent trouble attendant upon the secondary battery when the plates are confined, and when they are subject to constant motion; the destruction of the wooden cases owing to their being attacked by the acids which were spilled; and the fact that constant trouble was experienced with the connections getting eaten in two by the acid.

The Bristol lamp is very much on the same lines as the Pitkin, but smaller. The writer believes that no serious attempt has been made to introduce it for mining work,

though the writer knows of one lamp in which the outer wood case has been replaced by a metal case, which is stated to have given very good results. It is used by a managing director who does not often go down the pit.

It should be mentioned that all the secondary battery lamps were subject to the serious drawback that not much was known at the time they were invented, outside of a certain circle, of the behaviour of secondary batteries, and of the plates of which they were composed.

Mr. Niblett made also a determined attempt to produce a practical secondary battery miner's lamp, using a solid plate of peroxide for the positive plate. He also made several attempts to protect the connections between the cells, and between the cells and the lamp and switch, by gold-plating the connecting pieces, and by other methods; but the writer believes that at present none of the lamps made on the plan introduced by Mr. Niblett's Company are now in use in mines.

The Headland is another attempt of more recent date, and it is in many respects a very promising one, though the writer believes that it has not yet come into practical use.

Mr. Headland's idea seems to have been to imitate the old form of lamp exactly, in outward appearance, and he has succeeded in doing so remarkably well. As will be seen from the illustration, and from the lamp itself, it would not be known from the ordinary miner's oil lamp, except on a moderately close inspection. In appearance it is a bonneted Mueseler lamp, or one of a similar type, the difference being, on inspection, that in place of the oil-well there is a plain brass disc forming the base of the lamp, and that light is given by an inverted incandescent electric lamp, held inside the space usually occupied by the lamp-wick and the vapour that is burning. There is the same stout glass cylinder outside the incandescent lamp, that protects the oil lamp flame, and the glass is protected as in the oil lamp by vertical brass bars surrounding the glass, at intervals. The secondary battery of the Headland lamp is carried inside the iron bonnet above the incandescent lamp, and connection is made between the cells and the incandescent lamp by means of wires led to an ingenious form of switch.

The switch consists of the top and bottom of the lamp,

or rather of springs similar to, but larger than, the ordinary push springs used in house-bell work. Switching on and off between the battery and the lamp is accomplished by turning the bottom portion of the lamp through an arc of 90°, the springs attached to the top and bottom allowing this to be arranged.

So far as the writer is aware, the only special feature about the battery is, that it is made on Mr. Headland's special form, the plates being of the type of one of the many forms of secondary battery plate that have been introduced of late years, with the object of securing a larger quantity of active material. The battery is contained in the usual vulcanite case, and consists of two cells, and it occupies the space inside the iron bonnet.

The writer has seen and used this lamp underground, and it appeared to him to be a remarkably convenient form. It gives a light of one candle-power for the usual shift of ten hours, and weighs 4½ lbs.

The Sussman lamp, the only lamp of any kind which is in actual operation, consists of two vulcanite cells, each containing two lead plates of the usual secondary battery type, one supporting a coating of peroxide of lead, the other finely divided lead. The two vulcanite cells are held inside a tin case, which is lined with either paper or varnish.

The cells are closed, as are all those of the secondary lamps, with pitch run in on top of the plates, leaving vent-holes and spaces for the tops of the plates. The lamp is mounted on a small platform consisting of a block of vulcanite, which also carries the switch, and which is attached to the tin case forming the base by means of screws. Connection is made between the vulcanite top, with the lamp and switch, and the cells, by means of flexible cords similar to those used for pendant incandescent lamps, and which are fitted with small brass plugs which again fit into holes in the lead plates arranged for them. This arrangement is very convenient, as it enables the top to be easily and quickly removed for charging, and it also enables any top to be used with any cells, provided the tops are all made accurately to template. In the Sussman lamp also a couple of porcelain reflectors are carried, one above and one below the lamp, each being of a conical form, and with

the lamps intended for colliery officials there is also a reflector behind the lamp.

The reflector behind the lamp is of great service in the lamp used by the colliery officials, as when two or more are walking along a road underground they do not want the light of the man in front in their eyes.

But the great feature of the Sussman lamp, and that which has made it successful, as far as it has been so, is undoubtedly the material which is placed between the secondary plates.

The writer understands that in the early lamps trouble was experienced from three causes, all of which have been fairly well got over, viz. :—

1. The two vulcanite cells for each lamp were made in one casting, and the division-wall was constantly failing. They are now made in separate cells, two for each lamp.

2. The active material of the secondary battery plates chipped off, and made short circuits at the bottom of the cell in the well-known manner. This has been got over by placing two indiarubber bands, fairly thick, vertically round each plate, so as to lift it off the bottom of the cell, as in stationary batteries, and keep the plates apart.

3. The early form of the substance which was placed between the plates was of a gelatinous nature, through which the active material sometimes worked, again forming short circuits. This has been got over by forming the substance of a vegetable material, which, it is stated, successfully resists the passage of the active material through it.

The adoption of these improvements has apparently made the Sussman lamp a success, according to the accounts of the colliery managers who have used it in the county of Durham.

But the Sussman Company have also gone a step further, and have added to the lamp a gas-indicating apparatus, consisting of a smaller lamp, coloured red, as are all similar indications in a mine, and which lights up in the event of the lamp being in an atmosphere containing a small percentage of ordinary domestic illuminating gas, or hydrogen gas. The apparatus consists of a perforated metal cylinder containing a glass tube with mercury inside, and the usual bulb, practically a thermometer, on the outside of the bulb of which is placed some finely-divided palladium. The gas

impinging on the palladium generates heat, which causes the mercury to expand, and closes an electric contact between the battery and connections leading to the small red lamp, which then immediately lights up, and warns the miner that he must retire. When the gas is dissipated by the ventilating air current, or when the miner has retired to a place of safety, the small red lamp is extinguished. The writer saw the Sussman lamp with this addition tested at the Company's offices, the gas employed being ordinary town illuminating gas, and it appeared to work well. The question to be decided in these cases is whether it will stand the test of practical work in a mine, and whether it will respond to marsh gas. If it does, it may fairly be said that the problem involved in the Electric Miner's Safety Lamp is solved, the whole of it. It would certainly be better if the testing apparatus distinguished between different gases, but this will probably follow if the present apparatus turns out to be a really practical apparatus.

Secondary battery lamps are usually charged from the ordinary electric light service, the lamps being connected in series parallel. The Sussman lamps, which require about 6 volts to charge, are arranged in strings of 16, with a resistance and a small incandescent lamp in each series. In the writer's opinion it would be much better to charge each lamp, or rather each battery, direct from the circuit, transforming the current, if necessary, for the purpose, down to the voltage necessary for each individual lamp. When lamps are charged in strings, there is always the danger, as it appears to the writer, that one or more of the batteries may not be getting its current, while the remainder on that string will then be getting more than they should do. It is true that the presence of the incandescent lamp in each string *should* form a guide that all is, or is not, going right—that is to say, that approximately the right current is passing; but, as members are well aware, the incandescent lamp, especially the very small ones, though a very useful guide, is a very uncertain and a very inaccurate one. In the writer's opinion a service should be laid out at 6 volts, or whatever the charging pressure may be, divided into sections, very much as a tramway service is, each section having its own feeders, and there being as many pairs of connecting plugs, with flexible cords attached, as

the feeder will supply. Each lamp would then, on coming out of the pit, have its battery detached, as at present, and the battery would be put in its place on the charging table, the attendant only having to plug in the connecting wires in the holes where the connecting wires from the lamp are connected, and watch the instruments. Each section should have an ammeter showing the current going into the section as a whole, and each battery circuit should have a small ammeter showing the current going into each individual battery.

It will no doubt be objected that all this will cause expense, and that a thousand connections will be puzzling, and so on. In the writer's opinion the arrangement by which each lamp takes its current direct from the supply service will be far less puzzling than the series-parallel arrangement, and it will give the engineer in charge complete control over each individual lamp. The measuring instruments will add to the first cost, but instruments such as would answer for the individual battery circuits could be made, in the quantities that would be wanted if the lamp is adopted generally, at a small cost, while their use would save many a ton of coal lost to the collier and to the output of the pit for that day.

The writer imagines that his experience is the same as that of other members of the Institution, viz., that within certain limits you cannot make a mistake in adopting measuring instruments, and that their cost is repaid many times over by the command they give over the working of the apparatus, and the ability they confer upon the engineer to avert break-downs, and the equivalent.

Before leaving the subject of secondary batteries for miners' lamps, the writer would like to repeat the suggestion which he made in the discussion on Mr. Wade's paper before this Institution, and in the discussion on Professor Hele Shaw's paper before the Institution of Mechanical Engineers, viz., that the whole problem of the secondary battery requires to be reconsidered with a view to its being made very much lighter, and stronger.

As the writer understands the matter, the lead plate only performs the office which the carbon plate performs in the primary battery, with the addition that it acts as the support for the active material. If another metal could be arranged

to act as the electrode, and as the support for the active material, such as aluminium, the grids being formed of that metal, the result should be a very much lighter cell for the same work, and a very much stronger one.

The writer understands that something of the kind has been done, but that it was not followed up; a secondary battery plate being formed of an aluminium grid, with the active material, positive and negative, pressed into it.

From America also comes an account of a grid formed of some special vegetable material, which is stated to form with the active material, under the influence of the current, a solid mass that will take a charge in the usual way and deliver it.

The writer begs to commend these points to those who are interested in secondary batteries.

The Cost of Working Secondary Battery Lamps.

It is always difficult to obtain costs of working, especially when an apparatus is more or less in the experimental stage. Managers are loth to give figures, and the figures that would be obtained would hardly be accurate, on account of the extra expense which always attends the introduction of new apparatus, especially under conditions such as rule in this case.

Further, the Sussman lamp is the only one for which figures could be possibly obtained, as it is the only one in practical use, but the figures which the writer gives with reference to the Sussman lamp must be taken as only approximate for the above reasons.

The working cost of any secondary battery lamp is made up of :—

1. The cost of charging the batteries.
2. The cost of renewals of incandescent lamps.
3. The cost of renewals of battery plates and cells.
4. The cost of repairs generally.
5. The cost of attendance.

Some of the above can be obtained with fair accuracy, such as the cost of charging the batteries. This again is made up of :—

a. The cost of the current, and—

b. The cost of attendance on the dynamo, engine, and batteries while charging.

The following figures referring to the working of the Sussman lamp at some collieries in the county of Durham, for which the writer is indebted to his old pupil, Mr. Edward Evans, and Mr. Turquand, who were in charge of the lamps at the colliery in question, will be of interest, and are very instructive.

The figures all relate to a batch of 600 lamps, in use at the same colliery, but used in three shifts by three sets of men working at different portions of the twenty-four hours. The number at the colliery is now, the writer understands, 1,000.

The power consumed for charging the 600 lamps was 2 kilowatts, which may be taken as 4 h.p. at the engine. The current was furnished from a 100 volt supply service that was used for lighting the colliery.

The attendance on the 600 lamps, inclusive of repairs, charging, &c., was £6 17s. per week.

The life of the incandescent lamps themselves, the bulbs, was 800 hours, but the writer understands that this has been increased to 1,000 hours for lamps of the Edison-Swan Company's manufacture; for lamps of a French manufacture, the life was 500 hours; the cost of the lamps being, for Edison-Swan, 1s. 1d. each, and for the French lamps 7d. per lamp.

The life of the battery was nine months. At another colliery in the county of Durham, at which 300 lamps are in use, the life of the battery was stated to be six months, the life of the lamp bulbs 1,000 hours.

The breakage of batteries from falls, &c., was from four to five per week.

Putting these figures together, allowing 10s. per ton for coal used for the boilers, which can hardly be neglected in these days, 10s. per battery for renewals, and 1s. 1d. per lamp for bulb renewals, the writer makes out the running cost to be 7·8d. per lamp per week, probably with sundries which are not ascertainable, 8d. per lamp per week. It is only fair to mention, however, that the attendants could probably have dealt with 1,000 lamps, in which case the running cost would have been 6·5d. per

lamp per week, as compared with 2d. per lamp per week with the old oil lamp.

Mr. Evans has also given the writer the following information on the working of the lamp :—

The percentage of failures of lamps which were taken into the pit was, when he left the colliery, 0·25, though at first it was as high as 4·25 per cent., the percentage of failures of oil lamps under the same conditions being 1·25 per cent.

The measured candle-power of the lamp was 0·5 c.p., which, with the bonnet reflector, produced 1 c.p. in the beam.

The greatest output from the battery was 6·87 amp. hours, and the greatest efficiency 73 per cent., but both of these measurements were taken without the vegetable absorbent in the cells. Mr. Evans found that the addition of this vegetable absorbent, by raising the variation of the density of the acid in the cells, tended to soften the plates somewhat quickly, with the result that pieces of paste chipped off the plates and formed at the bottom of the cells, working down through the absorbent, with the well-known results, so that by the end of seven to eight months the plates began to come, the worst of them, for renewal.

The iron cases were made, Mr. Evans states, intentionally as cheap as they could be made, it being recognised that they would be soon eaten through when acid was spilt on them, and it being the intention that they should be renewed, when required, at a small cost.

The two colliery firms who are using the Sussman lamps are now making their own storage batteries, and making them very fairly too. The writer saw them being made at one of the collieries, by ordinary colliery workmen, very neatly, and apparently with very good results. This, again, would reduce the running costs.

In the early form of cells which were used when the lamp was first introduced into this country considerable trouble was caused by leakage between the cells. The two cells were formed in one mould, and holes were somewhat frequent between the cells, leading to the formation of a battery of high resistance between the plates of the two cells, the connection being already made by the ordinary cell to cell connection at the top. Hence the negative

plates used to go somewhat frequently. Making the cells separate cured this.

In Mr. Evans's opinion, the Sussman Company sacrificed mechanical strength for the electrical efficiency of the plates.

PRIMARY BATTERY LAMPS.

As already mentioned, a very large number of inventors have attacked the problem from this side, including Mr. Coad, who has made several forms of lamps, several French inventors, Mr. Maquay, who did a great deal to advance the matter, Mr. Schanschief, and the present writer. All, with the single exception of Mr. Schanschief, have used some

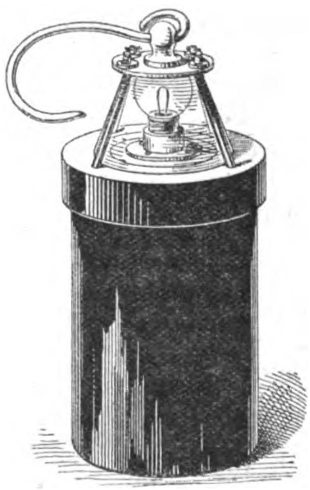

FIG. 3.—The Author's Primary Battery Electric Miner's Lamp.

form of salt of chromium. In fact, the changes have been rung on the salts of chromium, *ad infinitum*, so much so that a mere list would fill a good space.

So far as the writer is aware, the first really practical attempt to solve the problem by means of a primary battery was made by Mr. Maquay, on the writer's suggestion, in the year 1884. Previously to that the problem had been impossible, for practical purposes, because up to that time there was not in existence a primary battery of any kind that would maintain a constant current for several hours, unless it was of very large size and weight in proportion to

the work, quite prohibitive for the work of the miner's safety lamp; and even those batteries which were being used to furnish constant continuous currents at that time required a considerable amount of attention, and had not been tried when enclosed in the way the miner's lamp battery must necessarily be.

In the above-mentioned year, the writer was employed by a client to test and report on a primary battery the patents of which his client had been asked to purchase.

The battery tested so well, for that period, and maintained its current so uniform, and it moreover appeared to give such a comparatively large quantity of electrical energy in what was, at that time, a very small space and weight, that the present writer strongly advised both the patentee and his client that an attempt should be made to work out an electric miner's lamp from it. This was done by Mr. Maquay, and the lamp was exhibited by the writer before the South Wales Institute of Engineers. It was in rather a crude form, but it apparently contained all the elements of success.

The lamp mentioned, Mr. Maquay's first attempt at the problem, consisted of three cells in a vulcanite cylinder, the cylinder being divided vertically to form the compartments for the cells.

The cells were double fluid, a porous cell being contained in each. The elements were zinc and carbon, the zinc being in the form of a hollow cylinder surrounding the porous cell, and the carbon in the form of a plate inside the porous cell—the whole, carbons, zincs, and porous cells, being suspended from the top of the outer cylinder, which was also of vulcanite. The incandescent lamp was on the side of the outer cylinder, and the arrangement was much the same as in secondary battery lamps which were brought out at the time. A leather handle, attached to the outer cylinder was used for carrying the lamp. The outer cylinder was closed by the vulcanite top, a screw, working into a rod which passed down through the central division of the vulcanite cylinder, serving to keep the whole liquid-proof.

This lamp never came into practical operation. It was merely constructed to show what could be done in the matter.

Subsequently the present writer, with Mr. Maquay's

assistance and consent; worked at the problem, and produced a lamp, in which two and three cells were employed, according to the light required. The cells were of zinc and carbon, the carbon being in the form of half cylinders, hollow, except at the bottom, which was closed, the semi-cylindrical vessel forming the outer containing vessel of the cell. Inside the carbon cell was a semi-cylindrical porous cell, and inside that again a zinc rod. Two of these cells, forming together a complete cylinder, were placed in a copper cylinder, fitted with a bayonet-jointed cover and a substantial handle of the same material, the incandescent lamp being carried in a projection on one side of the outer cylinder, in a metallic reflector, and protected by an outer glass of the bull's-eye pattern.

The carbon cells were coated with an insulating compound, as was also the inside of the copper vessel.

As it was found that mining men wanted a larger light than was afforded by the current from two cells of this pattern, three cells were arranged inside a copper vessel of elliptical section, the other arrangements being the same as with two cells.

The solutions were the same as in Mr. Maquay's own lamp, viz.:—

In the zinc cell a very dilute solution of sulphuric acid, 1 of acid to 20 of water.

In the carbon cell, a solution consisting of certain proportions of bichromate of potash and sulphuric acid, with a small quantity of nitric acid.

A rubber pad covered the tops of the cells, maintained in its place by the copper top of the outer cylinder.

This lamp never came into practical use, nor did it ever get beyond a very cursory trial. Many difficulties arose.

The carbon cells refused to remain liquid proof, notwithstanding various materials with which they were treated. The matter of the connections between the cells, and between the cells and the lamp, proved a great stumbling-block to the mining men. They could not manage them, and the liquid from the cells was constantly spilled into the copper vessels and quickly ate holes in them. Added to this, the working out of the problem proved to be a very expensive matter, while absolutely no encouragement was given by the great majority of colliery owners. So the matter

was abandoned for the time, though much valuable information was obtained in the process of working the problem out as far as it went, such as the quantities of liquid necessary to maintain a current of a certain strength for a certain time, etc.

Mr. Maquay worked on at the problem for a considerable time afterwards, and, the writer understands, produced one or two forms of single-fluid lamps, in which carbon and zinc were the elements, various combinations of bichromates, with sulphuric acid, nitric acid, and other salts being used for the solution ; the zinc and the carbon, the writer believes, being held suspended from the cover of the outer cylinder, which was always of vulcanite, and the closing of which was, the writer understands, by means of pitch, or paraffin, or some similar substance run in hot.

Mr. Maquay also devised an arrangement for allowing the gases formed in the working of the battery to escape, by means of vent-holes, leading into a sort of gas chamber above the cells.

The writer believes that no serious attempt was made to introduce either of these lamps to practical work.

The next important lamp that was introduced was that of Mr. Schanschief, in which carbon and zinc were the elements, immersed in a salt of mercury. The battery was a single-fluid one, and it had the peculiar feature that the current was switched off by inverting the whole apparatus. The apparatus consisted of a vulcanite case, rectangular in section, with an inner case containing the elements attached to the usual block of vulcanite, and it was arranged that when the outer case was in one position the elements were out of the solution, while when it was inverted the elements were immersed.

The incandescent lamp was carried in a reflector, and protected by a bull's-eye on one face of the rectangle.

Mr. Schanschief also arranged a gas indicator, attached to one face of the outer case, consisting of a platinum wire inside a cylinder protected by a gauze front, and controlled by a switch. When the current was turned on to the platinum wire, it glowed very dull red in an ordinary atmosphere, but with more or less brilliancy if an inflammable mixture was present.

In the writer's opinion, the gas indicator was of very

little value, as the current taken by the platinum wire was too considerable to allow of its being constantly connected to the battery; and to be of service to the collier it should have been automatic.

In addition, it appeared to the writer to surrender a large portion of the most important advantage claimed for the electric miner's lamp—the absolute severance of the source of light from the surrounding atmosphere.

Mr. Schanschief's lamp was made in three sizes, weighing, when fully charged, $3\frac{1}{4}$ lbs., $4\frac{1}{2}$ lbs., and 5 lbs.

The smaller one contained three cells, and measured 4 inches square by 4 inches high. Each cell contained 15 fluid ounces of liquid, which, in consuming $\frac{3}{8}$ lb. of zinc in 48 hours, was stated to furnish a light of nearly 2 c.p. in the direction of the beam.

It was guaranteed to give a good light for from 8 to 9 hours, and the working cost was given at $\frac{5}{8}$d. per shift, or $3\frac{3}{4}$d. per lamp per week.

The writer believes that in this estimate nothing was allowed for the renewal of lamps, nor for other repairs that would be sure to be necessary. In addition, the estimate was formed on the supposition that the old material taken from the battery was returned to the makers, to be used up again. Mr. Schanschief gave the price of the liquid new as 4s. per gallon, while 3s. 7d. was allowed for the old material; but it was not stated where the old material was to be delivered for that price, and in the early stages, at any rate, the cost of collection would have an important bearing on the matter.

Mr. Schanschief's battery gave a remarkably steady current, though it was not tested, the writer believes, for any great length of time; and it is probable that the mercury salts formed in the working of the battery would have attacked the carbon plates, unless they were specially protected.

In the lamp which the writer worked out during recent years, and which he hoped to have placed on the market, aluminium was very largely employed.[1] The writer's first idea was to have simply an aluminium jar, with a vulcanite top, the top carrying the zinc, the incandescent lamp and any protection that was required; but his idea was also to

[1] The lamp is shown in Fig. 3 (p. 842).

have rendered any protection to the lamp unnecessary by making the lamp itself, the lamp bulb, of very strong glass, strong enough to withstand the ordinary wear and tear of a mine. He is aware that the strong glass would have absorbed some of the light rays, but probably less than are now absorbed by the protecting glasses of other forms.

If he had been able to carry out his idea in full, the first idea, the writer believes that it would have been difficult to find a simpler lamp, and he believes that when manufacturers turn their attention seriously to the problem of producing incandescent lamps of very low voltage and low candle-power, the portable primary battery lamp may still assume the simplicity he designed for it.

He was unable to carry out his design because, in the first place, he was unable to get any incandescent lamp-maker even to consider the matter, at any price; they were all too busy with lamps for the 200 and 230 and 250 volt circuits, and could not spare the time.

This matter of the lamp which could be produced drove the writer from point to point till he arrived at the present form, that in which the lamp of the lowest voltage he could obtain is made use of.

The apparatus, in its final form, consists of two single-fluid cells of ebonite, enclosed in an aluminium jar.

The elements are zinc and carbon, the zinc being in the form of a rod of sufficient size to last out a shift, just leaving the end which holds it in its place, which comes to cast up again. The zinc is not amalgamated. The carbon is in the form of a hollow cylinder, with a number of holes drilled in its length, and with its pores impregnated with sulphur.

The zinc and carbon are held by the cover of the battery, on which is also mounted the lamp, with its protecting glass. The protecting glass is surmounted by an aluminium plate, which supports the hook by which the lamp is carried, as in the Sussman lamp.

The cover of the battery is of ebonite, and it is held in its place by a collar of aluminium, which screws on to a flanged ring on the top of the aluminium jar containing the cells.

The ebonite cover is made in two parts, so as to form a bed for the connections, and for the arrangements for holding the zincs and carbons.

One portion of the ebonite top consists of a thick disc,

in which circular spaces have been cut, partly through its thickness, and in which slots are also made to form bayonet-joints for the carbons.

The carbon cylinders are coppered for a short distance from the top, the sulphur being removed for the purpose from the end, and to the coppered portion are soldered two brass cylinders, one having a flange and pins to form a bayonet-joint. The flanged brass ring which is on the outside of the carbon cylinder fits in the space prepared for it in the ebonite disc, the pins locking it in position after a quarter-turn has been given it, in the usual manner.

The inner brass cyclinder, in the carbon cylinder, has a thread screwed on its inner surface, and in this a small cylinder of ebonite screws, carrying another brass disc having a projection which, when the cover is in its place, is inside the carbon cylinder, and to which a brass cylinder is attached to the top of the zinc rod screws.

Slots in the ebonite disc also carry the connecting pieces, which consist of flat strips, substantial in section.

All parts which are exposed to the possible action of the acids are given several coats of a special varnish, which is put on at a temperature of 600° F.

Thus the connecting pieces, the brass caps of the carbons and of the zincs, except where actual connection is to be made, are all protected in this manner, as well as the inside and outside of the aluminium jar.

When the carbon cylinders are in their places, a thinner ebonite disc, having circular apertures for the passage of the carbon cylinders, is slipped on, and a special cement having been run into all the cavities, the two ebonite discs are brought together under pressure.

On the upper side of the ebonite disc is placed the lamp holder, which is also of aluminium, the protecting glass, which is also protected by three aluminium wires, and which are screwed into the aluminium flanged annular ring which closes the cells, and into the aluminium plate which is placed on the top of the protecting glass, and to which the hook is attached.

The built-up cover, with its zinc and carbon elements, is simply dropped into the cells, the annular aluminium ring is slipped over them and screwed down, and the glass and top plate put on, the whole presenting the appearance shown.

The incandescent lamp can be changed by removing the top aluminium plate. The solution consists of a mixture of chromic acid and hydrochloric acid, with a small quantity of sulphate of soda, and each cell gives rather over two volts, and will maintain it, with the proper quantity of the components, for eight hours without appreciable fall, and will continue to give a gradually falling current for another four hours, or longer if a larger proportion of chromic acid be put in the solution.

Gases are given off during the working of the battery, but, provided the cover is properly made, and the flanged ring properly screwed down, no harm results beyond a slight rise in temperature, the gases being dissolved in the solution.

The aluminium also does not appear to suffer from the acid which is spilled when the lamp is recharged, a sort of skin appearing to form which protects the metal from further action.

As will be understood, there were a great many difficulties met with during the process of working this lamp out, which occupied five years altogether ; the author's son, Mr. C. J. Walker, superintending the manual part of the work.

Only the purest carbons, of French manufacture, would answer the purpose, and it was found necessary to impregnate them with sulphur, just as the tops of carbons of Leclanche cells are impregnated with paraffin to protect them from attack by the chromic acid. In this the writer was assisted by Mr. R. W. Atkinson, an able analytical chemist of Cardiff, whom he consulted in this and other matters which arose during the working out.

Difficulties were experienced with the chromic acid, which at first was never of the same analysis, in two successive lots, and in portions of the same barrel, with the glass for the protection of the lamp, with the working of the aluminium, and other matters ; but all of them had been fairly well surmounted when the matter had to be abandoned for the reasons given, though not until it had been tried in several mines, and had been in the hands of practical colliers, who had done their ordinary day's work with it, to their great satisfaction.

The lamp weighed 3½ lbs. when fully charged, and gave a light of one candle-power for eight hours, with a gradually

falling light for another four hours, the light at the end of the twelve hours being about from one-third to one-half of a candle.

The working cost, the writer made out would be, at first, three-halfpence per lamp per shift, or say ninepence per week. This cost, however, was based upon the assumption that the materials would be all used, the unused residue being thrown away. As the whole of the materials were by no means used up, it follows that if the residue could be collected and worked up again, the cost would be very much less; and on this basis, which is perfectly practicable, by proper organisation, where a large number of lamps are employed, the writer made out that the cost would have come down immediately to one halfpenny per lamp per shift, with every probability of a further fall, which, considering the advantage to be gained by the use of a portable electric lamp in collieries, he felt sure would command universal acceptance, though it was higher than the cost of the present lamps.

In fact, the writer has been told by many eminent mining engineers that even the full price of three-halfpence per lamp per shift would not have been prohibitive, provided the lamp was absolutely safe and thoroughly practical.

The working cost of the primary battery lamp is made up of the following:—

1. The cost of the solution, less the value of the residue, if it is possible to recover and to utilise it; but the value must be taken after all charges for collection and recovery have been met.
2. The cost of the zinc or other metal employed, less again the value of the ends, after all charges have been met.
3. The cost of carbons and repairs to the battery generally.
4. The cost of the incandescent lamps, which would be the same, or nearly so, as for the secondary battery lamp.
5. The cost of attendance, which would include the mixing the solution where it was mixed at the colliery, the cleaning the battery, getting rid of the residue or arranging for its being sent to the

makers, recharging the battery, and other incidentals.

As no extended trial was made of the lamp it is not possible to make more than an estimate of the probable cost of all these, as the writer has done, the total figure being that given above; but it may be mentioned that plans had been worked out for charging the batteries quickly, the arrangements for the purpose being very similar to those in use at most collieries at present for filling the oil lamps, and for emptying them when they come out of the pit, with such modifications as would be necessary on account of the use of the strong acids employed, and also with the addition of special arrangements for facilitating the emptying and filling of the batteries that have been used, in somewhat similar conditions in other industries.

The writer was making arrangements to try a number of lamps for an extended period at a colliery in South Wales, when he was obliged to give the matter up.

He had not attacked the problem of indicating the presence of gas, but it was his intention to do so, and in the same manner as he had attacked the battery problem, viz., by an exhaustive series of experiments with every known substance that there was the smallest likelihood of achieving success with. His idea was that what was wanted was something attached to the lamp, not necessarily worked by the current or in any way depending on the current for its existence, that would change colour in the presence of gas, and, if practicable, give a different colour for the different gases met with in collieries. He believes that it is perfectly practicable, but, like other things, it will cost money to work out. Meanwhile he had made some notes that may be useful if the problem is ever attacked by any one with sufficient perseverance, and sufficient money, to command success.

Another form of primary battery lamp which has been brought to the writer's notice since the above was written, which is based upon completely new ideas, will probably be of interest to the Institution. Many members will have heard of it, the late Dr. Hopkinson having reported very favourably of the battery for another purpose. It is called the Doe battery, and comes from America, and is a single fluid battery. In the electric miner's lamp which has been

constructed with this battery four cells are employed. The four cells form the four equal sectors of a cylinder of ebonite, which is divided into compartments by two diametrical divisions at right angles to each other. The divisions do not come up to the top of the cells. This is one of the peculiarities of the battery. In each cell is a grooved and perforated carbon cylinder, and inside the carbon cylinder is a cylinder of ebonite also hollow, and also perforated, the object of the perforations being in each case to secure the flow of the exciting liquid. Running down between the vulcanite cylinder and the carbon cylinder is a platinum wire enclosed in a vulcanised rubber tube. One end of the platinum wire forms a lacing, a sort of cat's cradle across the bottom of the vulcanite tube, and the other is pegged into the carbon of the next cell, a carbon peg being used, a hole having been drilled in the top of the carbon for the purpose. Into the vulcanite cylinder is dropped a hollow cylinder of zinc, after the cell has been charged with the exciting liquid, which consists of sulphuric and other acids, and other chemicals which are kept secret, the inventor stating that not only are certain components necessary, but they must be mixed in a particular manner. As will be seen, though the arrangement is a complete inversion, when the zincs are in their cells, they complete the circuit, by the fact of their immersion and by the fact of their contact with the platinum wire, which is again in connection with the next cell.

The weight of the lamp, one of which is shown, is stated to be only 2 lbs. when fully charged. The zincs are amalgamated.

The liquid is sold by the owners of the patent at 2s. per gallon, and the zincs, ready for use, at 2s. per lb. One gallon of liquid is stated to last for 14 charges, and one pound of the zincs for the same time, in the miner's lamp made with this battery. This would give 1s. 8d. as the running cost of the battery without allowing anything for attendance, lamps, repairs, &c. The first cost of the battery is also high, owing to the necessity for using platinum in the manner described. On the other hand, the marked simplicity of the battery speaks very loudly in its favour, and the writer is of opinion that further investigation would probably enable the inventors to reduce both working and

running cost. He is informed that they have hardly touched the problem of a miner's lamp seriously yet.

Conditions Necessary for an Explosion in Colliery.

In conclusion, it may be of advantage if the conditions of explosion are considered.

Mining men are terribly afraid of anything electric where they may possibly have gas at any time, and they are under the impression that anything which will give a spark will also fire the gaseous mixture that may be present. The writer has heard it alluded to as a good joke, that any one could doubt for an instant that a spark, being at a high temperature, could and would fire gas if present. Yet it by no means follows that a spark would fire gas.

On the other hand, the writer has been told by other mining engineers that it is somewhat laughable to make such a trouble about sparking, when the strata itself, in falling, in the ordinary process of coal-getting—not the coal, but other strata such as sandstone which sometimes overlies the coal—gives rise to huge sparks. One mining engineer told the writer that he had seen the face of the coal, when the roof was coming down, a mass of flame.

Again, the gas which is found in coal-mines is not the same as our domestic illuminating gas. Its chemical symbols are CH_4, while those of the domestic illuminating gas are C_2H_4, which means that it does not ignite so readily as the heavier carburetted hydrogen. The larger proportion of carbon in the domestic illuminating gas apparently makes it ignite more readily, as can be easily proved.

Again, in order that an explosion may occur, assuming that a spark which will ignite gas is formed, there must be the conjunction of conditions—the mixture of gas and air within the proportions named, and the spark passing at the same instant: a very unlikely thing with such a spark as could be formed from any miner's portable lamp, because in all modern collieries the whole of the working face of the coal, the place where the gas will be liberated if at all, is swept by a powerful current of air, which quickly dilutes it below the inflammable mixture.

After all that, however, there is the other very important fact that the spark to be obtained from the two-cell battery,

weighing from three to four pounds, is incapable of igniting an inflammable gaseous mixture.

It should be explained that the idea that temperature alone is necessary for the ignition of an inflammable gas is incorrect, as a little consideration will show.

In the coal-mine, as everywhere else where men live and breathe, the gases of which the atmosphere is composed are in constant motion, apart from the motion which we know as heat, whether the motion takes place in the molecules, or in the ether in which they are suspended. The molecules of the gas are in motion from various causes, one being the pressure of the ventilating current, others being the various convection currents that are set up, and so on. Hence, when heat is delivered to any portion of the molecules, to any group of molecules, if it may be put in that way, the heat so delivered is distributed to the molecules around, and is dissipated very quickly; so that, unless a certain quantity is delivered, the temperature of the gases in the neighbourhood of the spark is hardly raised at all, as the heat has been distributed over such a large area.

Again, in order that ignition and subsequent explosion shall take place, it is necessary that sufficient heat shall be delivered to a certain group of molecules to enable them to divide into their elementary components.

If we consider the process of ignition and explosion, we find that we have first a mixture of atmospheric air, consisting of oxygen and nitrogen gases with a certain quantity of a carburetted hydrogen gas, and that when ignition takes place the components of the carburetted hydrogen gas become disassociated, and each individually combines with its equivalent of oxygen gas, forming either carbonic oxide or carbonic acid gas, or both and water. The net result of the operation is the liberation of a large quantity of heat, which, if other conditions are favourable, extends the decomposition and the recomposition, with the result that a further quantity of heat is liberated, and it is this heat liberated by the combination of the carbon and the hydrogen with the oxygen which, by causing the resultant gases to expand very rapidly, gives us what we know as an explosion. That is to say, we have at one instant three gases, mechanically mixed together, occupying a certain space, and perfectly harmless as long as they are content

to occupy that space. The next instant we have two or more other gases which, under the influence of the heat liberated, seek instantly to occupy a space many times as large; and when the space is limited, destruction results. Now all this is due to the liberation of heat; but first of all it is necessary that heat shall be delivered to the gases, in order that they may be able to split themselves up into their components, and sufficient heat must be delivered to the gases to raise the molecules which commence the operation to the temperature at which they become divided.

Hence it will be seen that it is not a spark *per se* which is able to ignite an inflammable mixture of gas and air, but a spark, or any other source of heat which is able to deliver heat to the gases at a certain rate, and to deliver a certain minimum quantity of heat.

From the writer's experiments, which have been borne out practically by those of other experimenters, the rate of delivery of heat that will ignite a mixture of ordinary illuminating gas and air is 20 watts. This he finds is the minimum rate, and as pit gas is less sensitive to ignition, it follows that the rate for its ignition would be higher.

The quantity of heat to be delivered to the gases depends upon the circumstances.

Now the two-cell electric miner's lamp, either primary or secondary, cannot deliver energy at the rate demanded, nor can it deliver the total quantity required, and it must therefore be absolutely safe as far as causing an explosion is concerned.

It is right to mention that in some experiments made in Germany, a four-volt lamp was actually made to ignite a gaseous mixture, but it was under conditions that could never occur in practice. The filament was laid bare, and allowed to burn naked, in an atmosphere of gas and air, and we have not been told what pressure was behind the current, which would make a considerable difference.

It is also, perhaps, as well to note that experimenters, Mr. Mordey among them, have ignited an inflammable gaseous mixture with a low-voltage battery when an electromagnet was included in the circuit; on breaking which a spark passed. In these cases the spark was delivering energy at the required rate, and in the required quantity,

though the voltage was low, because it was possessed of a store of energy in the electro-magnet, the stored energy being delivered when the spark passed.

It may also be useful to mention, in connection with portable batteries for collieries generally, the fact that in a few collieries in the North of England hand lamps in various forms, deriving their current from two or more dry cells, are being used as occasional lamps by deputies, overmen, and others. The batteries are expensive, considered as the source of current, as against the cost of either the oil lamp or even the most expensive of the primary or secondary battery lamps, but the convenience is so great that the expense in this case does not count. The lamps are used for a short time on one or two days in the week, principally on Sundays, and appear to stand well. As is well known, the dry cell has been enormously improved during recent years.

In conclusion, I wish to record my thanks to Mr. Harrison Bulman for his kindness in lending the photographs from which were prepared the lantern slides used in illustration of the paper.

The President.

The PRESIDENT: The two papers will be discussed together, and I will first call upon our old friend Mr. Kapp, who is here from Berlin.

Mr. Kapp.

Mr. GISBERT KAPP: I think we ought to be much obliged to Mr. Ravenshaw for having read such a very practical paper, and especially have we to thank him for having given us a list of failures. I was astonished to find the list so short. I do not know whether he has withheld a good many other failures, but I suppose not. When you consider that the whole list of failures which have come under his notice—and he is an expert in this matter—occupies less than three pages of the paper, I think we can congratulate ourselves that electricity in mining is a very safe agent for working. I should like to mention a few details, not in order to criticise, but to elicit further information.

I notice, under the heading "Switch Gear for Motors," that the author advocates the putting in parallel with the shunt coil a non-inductive resistance of twice the resistance of the fields. Of course, this is a very old device to kill a spark at breaking an exciting circuit. But it is expensive. If the resistance is twice the field resistance, you will spend 50 per cent. more of your power in excitation. And although the coal is on the spot, I do not think colliery managers will agree that a part should be wasted instead of sold. I would ask Mr. Ravenshaw why a well-known device is not used for breaking the shunt circuit in a motor which is used for lifts and for other purposes where a motor has to be switched on and off frequently. What I refer to is simply the shunt being connected across the ends of the starting resistance, and if you break at that juncture you have the armature as a by-pass to the dis-

charge of the shunt current. Perhaps the author will say more about that in his reply. Another device which can be used, and which has recently been invented, is very useful for motors. It consists in a variable resistance, not in liquid, but in powder form. The resistance consists of a graphite powder, and an electrode dips more or less into the graphite, thus altering the resistance. On switching off, the current is gradually diminished, and you can switch off absolutely without spark. Mr. Kapp.

Another detail to which I would call your attention is the safety device, which the author seeks in his drum armature. He says justly that in a smooth core drum armature the full potential difference exists between adjacent wires. We knew in the old days the trouble that we had with drum armatures where the wires were side by side. If a fault occurs a burn-out takes place at once, and the whole machine is crippled; whereas, in a Gramme machine only one coil is crippled. But I think this argument is not a very serious one, and it applies, at any rate, only to smooth-core armatures. If you have an armature with grooves, you naturally put the wires of even numbers at the bottom, and those of odd numbers at the top. Therefore this tendency to a break-down vanishes. Again, armatures with teeth are much to be preferred when you have to deal with rough work like motors for mines; and therefore I do not think we shall be able to utilise this safety device. It is better to prevent the breaking down, and that can be done by insulating properly. The author says an armature was insulated with paper. I do not know whether he means by that that the wires were wrapped round with paper, or that the smooth core has been insulated with paper. Neither is admissible. The core ought to be insulated with mica cloth, and the wires ought to be double cotton-covered and braided.

I should like to ask Mr. Ravenshaw whether he has purposely omitted to mention two-phase or three-phase currents in his paper? He says he has not had any experience himself with them; but I would like to ask him if three-phase currents are used for mines? It seems to me that if they were, a good many of the difficulties which he has pointed out in working would vanish. One of the difficulties not only in mines, but in any places where there is much carbon or other dust, is a choking up of the air passages. I know of one place where the armature always broke down. It was beautifully ventilated, but the coal-dust came and filled up the holes and choked up the armature, and caused it to break down. Another difficulty arises in cases in which there is a commutator, and coal-dust is present: there is generally some corner where the dust can accumulate. These are difficulties which I maintain you can obviate by using polyphase motors. It is perfectly possible to make a polyphase motor which will stand any amount of rough usage. About six years ago some of these motors, each of 60 H.P., were installed in a large drainage scheme. On account of the nature of the ground it was impossible to put down separate steam engines, and it was found cheaper to put down a generating station and distribute the drainage pumps, which were electrically driven, along a dyke, at about twelve miles from the

Mr. Kapp. generating station. That was in a place which had previously been under water for half the year, and which was therefore very damp. One motor, before it was erected, rolled down into the ditch and got a soaking for two or three days. That motor broke down. The other motors which were left out in the rain got wet, but they did not break down on being started. The motors, although under roof, are exposed to heavy sea fogs, but they are working to this day, and there has not been a single hitch. I contend that the fog, with salt in it, coming from the sea, is far more dangerous than coal-dust. Yet it is possible to find motors which will stand it—and those that I am speaking of were 5,000-volt motors. Therefore I think the spoiling of the insulation by coal-dust would be obviated if you were to use three- or two-phase motors where you have no exposed parts. You need not have slip-rings on the armatures, because the efficiency is not much less if you work them without. You have absolutely no exposed metal part in those motors, and I do not see how you could spoil the insulation if you were even to throw a sack of coal on to them. I will put it in this way: there is no more disadvantage in using three-phase than other kinds of machinery for certain kinds of work. For instance, here we have mentioned pumping and coal-cutting. About coal-cutting I cannot say much, as my experience is very limited; but for pumping, a three-phase motor is very suitable, especially now that we have piston pumps to go at fairly high speed. If these power schemes come into being I hope the frequency adopted will be 25. This is a very convenient frequency if you want to use converters for tramway work, as well as for motor work generally. You will then be able to put a two- or three-phase motor straight on to the shaft of the pump, and that will be a very simple arrangement. You can have them direct-coupled, and the little extra loss which occurs by reason of having a squirrel-cage instead of a wound rotor and slip-rings will be counterbalanced by the absence of gearing. But there is one particular kind of work in mines which is very heavy, where you cannot use alternating currents, and that is for hoisting. In the Rhineland that is a very important part of electric mining engineering. Recently some improvements have been made in the shape of a combination of a secondary battery with the motors. I have the figures of one installation which I have had to go through lately. It is a mine 700 yards deep, and the speed works out roughly at 60 feet a second, so that the whole time for hoisting is about 40 seconds. The plan is to use a balance system with tail ropes hanging from the two cages, so that the system may be balanced in any position. If you do not have a tail rope, the tendency will be that as soon as one cage gets a little lower than the other it will run to the bottom. Previously a pulley was fixed below, in the bight of the balancing rope, but now one simply lets the rope go through a timber grating, with renewable pieces where the rope cuts the timber. If you hoist in the ordinary way, a generator of 1,600 kilowatts and motor of 1,500 will be required. By using two motors under the same sort of control as for a tramway in combination with a buffer, a battery of 1,000 kilowatts and a generator of 900 kilowatts, the same work can be done as with a motor of 1,500 kilo-

watts. There is a great saving. The cables can be smaller, and the generator is loaded very evenly all through. Mr. Kapp.

Mr. A. P. TROTTER: On first receiving this paper it was a great disappointment to me to find how very short it was. But on looking it through, I think you will agree with me that we seldom find a paper so solidly packed with facts, and facts culled from actual experience, such as not many experts give away; for the conditions of this kind of work are such as it is practically impossible for an outsider to predict, and only one who has seen the difficulties which might be met with can realise what they really are. Coal-mining work is at present in the (in some respects) happy position of having but very few regulations attached to it. But perhaps regulations will shortly be made in this industry by somebody, and in making them experience of the character given by the author will be of importance. For instance, I believe some little trouble has been anticipated from sparking motors in mines, particularly in gassy mines. So long ago as Feb., 1891, in the paper read by the brothers Atkinson at the Institution of Civil Engineers, Vol. civ., the question of electrical machinery in mines was carefully gone into. But so little has been heard about coal-mine working that it does not appear to be recognised by people who have motors to sell, particularly motors which have been used in countries where the seams are soft instead of being of rock, as in England, and where perhaps there is no fire-damp, that such motors are not fit for use in fiery mines. It seems to be forgotten that as long ago as 1887 coal-cutting motors were made absolutely gas-tight, and therefore, externally sparkless. Mr. Kapp has suggested that a three-phase machine could be enclosed and put into the most fiery gas mixture that you can have, but the motors I speak of were actually so run by the Messrs. Atkinson. Of course they have the disadvantages of a closed motor, which warms up, and therefore has to be made bigger. But even when that paper of the Messrs. Atkinson was read some extraordinary suggestions were made to avoid explosion of gas. Most scientific suggestions were thrown out, and I think somebody suggested the forcing in of carbonic acid gas into the enclosed motors in order to neutralise any tendency to explosion. These motors, for coal-cutting and other purposes, were made by the now almost forgotten firm of Goolden & Trotter, and they were designed by Mr. Ravenshaw. Mr. Trotter.

Professor C. LE NEVE FOSTER: As one of His Majesty's Inspectors of Mines, I have been impressed with Mr. Ravenshaw's paper. I should say a word, I think, on behalf of the miner, in correction of one sentence. Mr. Ravenshaw very properly says that the cables going down a mine-shaft ought to be protected, but I think he goes a little too far when he says that corves and other trifles are in the habit of falling down shafts. At all events, if they do—and certainly these accidents do occur sometimes—they are not frequent, and, judging by the results as far as the injuries to persons employed are concerned, they must be very infrequent indeed. Then in the case of haulage, Mr. Ravenshaw says: "The author cannot quote a single instance in which electric locomotives have been employed in coal-mines;" but surely those who have been on the Continent or in America, or in Prof. Foster

Prof. Foster. Vancouver, will say that they have seen electric locomotives in use. Possibly Mr. Ravenshaw means that he has not seen at work electric locomotives worked from an accumulator. But even that kind of thing may be seen. Accumulators carried in a tender and the motor in an enclosed case may be seen in the north of France, and access of fiery atmosphere into the case carrying the motor is prevented, not by compressed carbonic acid gas, as mentioned by Mr. Trotter, but by compressed air. This is constantly flowing out of the case, and so preventing the entry of any inflammable gas.

Now, turning to Mr. Walker's paper, he has insisted very strongly upon the difficulty that the collier has in carrying a heavier lamp than the one now given to him. The collier is perfectly right; he has much muscular work to do, and he naturally does not like to expend energy in carrying more weight than is necessary. But surely, on the other hand, the collier can be relieved from much of his toil. Are we not foolish people, at the beginning of this enlightened century, to put a man to work in the constrained position, which has sometimes to be adopted, and expect him to work there, expending muscular power for many hours, simply cutting a groove into soft material? If you go to the shipyards, you will find men caulking, chipping, and doing riveting work with pneumatic hammers. Surely when all the work which has to be done is to cut a groove in a soft rock, in places where comparatively cumbersome coal-cutting machines cannot be conveniently employed, the work might be done by a pneumatic chisel, and the implement could be used in any position required. If that were done in coal-mines, very much muscular labour would be saved, and the men would simply have to hold the tool to do the work; and then the miner would not mind carrying another pound weight in his lamp. With regard to these lamps, Mr. Walker has stated that a very limited number of the Sussman lamps are used in this country. Of course that depends upon what Mr. Walker means by a "limited number." I was told last year that 2,000 were used in this country, 2,500 in Belgium, and 200 in Australia. So I think the lamp may be spoken of as fairly extensively used, though it is true that the proportion which 2,000 bears to the total number of safety lamps in the kingdom is not great. On page 820 of Mr. Walker's paper he states that two gases are present in old workings, carbonic acid gas (CO_2) and carbonic oxide (CO). I fancy he will not find the carbonic oxide given off in old workings naturally. He would, of course, find it in mines after explosions or after a fire; but I will ask my colleague, Mr. Atkinson, to confirm me on this point. I think Mr. Walker will find that carbonic oxide is not given off in old workings.

Then with regard to locking the lamp, he says the most successful method of locking the lamp is to call in the aid of electricity. Is not that going a little too far? Is not the common lead rivet a successful means of locking the lamp? Mr. Walker is perfectly right with regard to the value of the electrical lamp for examining the roof. It is a lamp where you can hold the light close to the roof, or hold it sideways, and work well with it; whereas with the ordinary lamp you cannot hold the light in that position. Certainly you can make a better examination

of the roof with the aid of the electric light than with the ordinary lamp. I can believe, with Mr. Walker, that a good lamp will be the means of preventing some of the accidents from falls. Mr. Walker said further, on page 823, that each non-fatal accident to men in the mine costs the colliery manager £60 and upwards. Surely that estimate is a little high for non-fatal accidents. I have not seen in use, nor indeed have I ever seen before, the ingenious appliance for the detection of gases. But, before speaking about that, one would like to examine the contrivance, to see it in actual operation, and to test it underground. Of course it has the objection that it will only, as I understand Mr. Walker, reveal the presence of fire-damp, and not the presence of carbonic acid gas. Prof. Foster.

I have to thank you for listening to a non-electrician, of a class which I hope is rapidly dying out—that is to say, a mining engineer without electrical training. But I hope in the future that every mining engineer, no matter whether he is engaged in mining coal, ore, or stone, will receive training in electrical engineering.

Mr. W. M. Atkinson: If Dr. Foster has found occasion to apologise for his lack of electrical knowledge, I am quite sure I must do so ten times more, because my electrical knowledge is of the most superficial kind, and any remarks that I may be allowed to make here will be from the mining point of view. There is one question in reference to Mr. Ravenshaw's paper upon which I would like to say a few words, and that is as to the danger of explosions from sparking. I think up to the present time the great majority of motors underground have either been in pits, where there is practically no danger from fire-damp, or in those parts of fiery pits where the gas would not be likely to reach them. They are now being introduced for coal-cutting, and if they are used in fiery mines for this purpose, the question is a serious one. The only plan I have seen adopted of getting over the danger of sparking is by enclosing the armature and commutator in a solid metal case, and from the instance I have in mind I am quite satisfied it is practicable to do that. But it would be a great advantage if, when the machine is designed, that question were more particularly borne in view than in this case. The openings which have to be closed should be so designed that they are of the simplest possible character, with plenty of surface for the material, which is put between the two plates of iron—plenty of bearing service; and it should be specially designed with the view to the closing in of the sparking parts. Mr. Atkinson.

With reference to Mr. Sydney Walker's paper, my impression is that the chief reason why electric lamps have not been more largely introduced than they have been is their liability to get out of order. In every other respect I think an electric lamp is superior to the ordinary safety lamp, except in the matter of weight. I personally do not attach as much importance to weight as many others do, provided a better light is yielded. I agree with Mr. Walker that the electric lamp is safer than the ordinary electric lamp, because after all, even if an electric lamp would fire gas when it was broken, so also would an ordinary safety lamp. As to the gas detector, no doubt the

Mr. Atkinson.

absence of such a device is a drawback in the electric lamp, and mining engineers will be very glad to see that difficulty got over. But I do not think that is such a serious question as to prevent the very much larger use of the lamps if one were brought forward which would stand the more or less rough usage that these lamps receive in mines, because a proportion of ordinary safety lamps could be used for the detection of fire-damp.

Mr. Walker refers to a mercury switch in one lamp. I do not like that idea because of an experience which I have had with it myself. The lamp is liable to be extinguished by a jerk, and if that happens at a critical time it might put the user in danger. I have myself been put into danger by my lamp jerking out when a set of tubs was coming on down a plane, and when I was trying to get out of the way of them. I think a switch which is not moved too easily is desirable.

With reference to carbonic oxide in mines, my experience is that gas is never found in a mine unless it is either the product of explosion or combustion—it may not be actual combustion, but it may be what I may call incipient combustion. It is never a natural product of the mine under normal circumstances. It is due to some chemical action of an unusual character, as far as coal-mines are concerned at any rate.

Mr. Mitcheson.

Mr. G. A. MITCHESON: I am a mining engineer with a limited knowledge of the technical details of electricity, but I have been much interested in Mr. Ravenshaw's paper, and should like to say a few words on the subject. With reference to cables in shafts, I should be glad if Mr. Ravenshaw would tell us how he proposes to hang and to protect them. I agree with Professor Foster that we do not hear of corves, or pit tubs, tumbling down shafts every day, but pieces of coal do occasionally fall down, and although it may of course be argued that coal, being of a friable nature, would break up in course of its descent by striking the sides of the shaft, still there is always more or less risk of injury to an exposed cable. The cable may, of course, be protected by placing it within an iron pipe; but in that case there is the difficulty of getting it into the pipe, if the cable be a large one, although the cable may obviously be divided into sections. In this case, if any accident were to happen, necessitating the removal of a section, such removal of a section and the substitution of a new one might cause considerable trouble. There is, however, another difficulty in connection with this problem. It seems to me that the amount of moisture which is always to be found, even in a so-called dry shaft, will attack the insulation of the cable at the point at which it is held by the wooden glands unless, of course, adequate protection is provided. I should like to hear what Mr. Ravenshaw has to say about that.

With regard to the risk of explosion from sparking in the mine, personally I do not look upon that as very serious, so far as the coal cutting is concerned. Your motor must be in a gas-tight jacket, because of the conditions under which it works. You must remember that it is working in the midst of dust, from which it must be protected. Per-

sonally, I think there is more risk from fire than from explosion, because the cables are carried along dry, and fairly warm, roads; as they are fixed to timber, you have all the risks in connection with falls to take into account, and where an arc is formed a fire may very readily be produced in one of these dry-timbered roads with most disastrous effects. Mr. Mitcheson.

With regard to the question of switches, I think they want protecting as much as the motor. There is one view which I take as to the application of electric power and electric lighting in mines, and that is that we as mining engineers have to make up our minds to keep the mines safe. For instance, there is the difficulty about the lamps standing rough usage. It is not very long since miners worked with candles, and it was a great deal of trouble to get a miner to use a Davy lamp. Then the glass lamps came in, and it was thought they could not be used because of the risk of breakages; but now the glass lamp is all but universal. I have no doubt that, if the miner gives his attention to it, he will be able to take more care of the electric lamp than he has taken of the oil lamp. As far as he is concerned, he does not think much of the extra weight of the Sussman lamp. I have a few of them at work, and as a rule the man does not care for these new things. It is the unanimous opinion of the men that the Sussman lamp is of great advantage to them, and they are strongly in favour of it. Undoubtedly it gives a better light, and in the places where my men use it they would have to take two ordinary oil lamps. One electric lamp certainly brings as much benefit as the two oil lamps.

I do not agree with Mr. Walker with regard to his figure of the weekly cost of up-keep of the lamps. It is true I have only a few of the lamps at work, and they have not been in use very long; but up to the present they have cost much less than Mr. Walker's estimate.

Personally, I do not think very much about the detector; I have not had much experience with it, but I have certainly tried it. Sometimes it will work; at other times it will not. I think if we can get the electric light we can afford to keep an oil lamp in the place in the hands of a responsible person for the purpose of testing the mines.

Mr. R. HOLIDAY: I am a sort of rough-and-ready electrical engineer, who has laid out a 1,000 horse-power plant comprising 60 motors, and am very glad of the invitation to come here. As to the shaft cables, that is one of the great difficulties which have been met with in putting electricity into mines. Cables have been put in in boxes filled up with bitumen and substances of that sort; also lead-covered cables are used; and after a time, owing to the very corrosive waters which are met with, the lead has been eaten away. Where the cables have been in boxes all the way down and have given way, the whole of the cables have had to be ripped out in order to find out where the fault was. So in putting cables down—and we have 25 cables down our shafts—we suspend them from the top to the bottom without any intermediate support whatever. I designed a rough-and-ready insulator which would carry two tons, which has a clam, just as one would suspend wire ropes for cage guides from the top of the shaft. This clam is insulated in a simple way, but it does its duty satisfactorily. The cable hangs clear from Mr. Holiday.

Mr. Holiday. the surface, and it does not touch the walls; therefore, instead of buying an expensive armoured insulated cable, we have a triple-braided cable (though a bare cable would do). In this way, if the man examining the shaft touches it, it saves him from getting a shock. It is true that water streams on to the cables in some places, but as the current cannot get to earth there is no fear of leakage; and I may say that we test our cables every week, on Sunday evenings, with the megohmmeter, and a record is kept of these tests. So far from the shaft cables being the chief trouble, we have never had a breakdown in them. The method I have spoken of is very much cheaper in first cost, and also in upkeep; and there is the great advantage that the cables can be examined constantly. As to corves falling down, that, unfortunately, has happened once in one of our shafts, and it was found that the cables had been scraped all the way down; but they did not suffer either in the matter of insulation or mechanically. If the cable is hung clear of the shaft-sides from the top to the bottom, there is nothing for an obstacle to catch against in falling from the top. The one weak part about this system is the place where the cable turns in to the porch at the bottom. Before turning into the porch we stop with our braided insulation, join on an armoured cable, and turn in with it to an insulator fixed in the roof of the porch; and so when any water runs down the cable it drips off without running to the insulator. Though the shafts have had to be repaired, and men have let bricks fall down, there has been no accident with the cables. So I do not think we can say with Mr. Ravenshaw that we should stick to armoured vulcanised bitumen cables. Putting in a cable which has to be fixed all down the side of the shaft is a very expensive matter, because a heavily-insulated and armoured cable has to be used every time, and the fixing of boxes and the like in shafts is expensive. If a fault develops it is difficult to locate the position of it. We have shafts of the following lengths:—600 yards, 400 yards, and 330 yards. In putting cables into these, all we do is to order them to be in one length, hard drawn—for instance, 600 yards $\frac{19}{12}$ths S.W.G., which leaves a factor of safety of 8, so that there is not much fear of their breaking by their own weight. We have never found any sign of stretching in the cables, although we have had them in since 1893. I think that is a very good test. The drum of cable is run into the cage, and is lifted up so that it can revolve on a bar which rests on the sides of the cage, and then the end of the cable being secured to the insulator, the cage is lowered, and in this manner two cables 600 yards long have been hung in an hour.

With regard to shunt motors, and Mr. Kapp's remarks on them, we connect the shunt from the first step of the starting switch. It is arranged so as to keep contact with that first step, and we have never had trouble with the shunt breaking down the insulation of either motors or mains so long as the shunt was excited from the first step. As to liquid resistances, I would not have any of them near a colliery. I have had a few, but they did not succeed well. The Gramme armature, in my opinion, is the one for coal-mining. One of the conditions in coal-working which one must keep in mind is that

Mr. Holiday.

there is only a certain time in which to draw coal. Under the new Miners' Eight Hours Bill our time for drawing the coal will be limited still more, and it will leave very little time in which to work. Every half-minute lost is a consideration. If everything goes well the coal-winding begins at 6 o'clock a.m. and continues without cessation, except from 10 to 10.30 a.m., until 4 o'clock, and anything that stops a single wind of the cage in working hours is so much loss. Therefore a matter to consider in a coal mine is, if anything goes wrong, what is the quickest way of repairing it. The haulage motors are as important a part as the winding engines. If the coal is not ready at the bottom, it follows that it cannot be wound to the top, and any fault that develops in a haulage motor stops the working of the pit. That motor is the best which can be repaired most quickly. Mr. Ravenshaw advocates the drum armature, and also the enclosed motor. He says colliery engineers do not care for the enclosed motor because some day it will be run with the covers open. I prefer to have it open where it can have fresh air from the intake, and it can then be readily inspected. The motors which are made nowadays are very nice in appearance and efficiency, but they have got ridiculously small from the colliery engineer's point of view. A maker recommends his motors because they weigh half as much as somebody else's for a given output. I grant that the armatures are beautifully wound, and the wires are laid compactly and neatly, but if anything happens to such an armature and you want to get one of the coils out, you have to pull the whole armature out, and probably have to send it to the makers. We have big Gramme armatures with rough-looking windings, and when anything goes wrong with these they telephone to the surface, "Our motor has flashed." A man immediately goes with a pair of pliers and a piece of wire, cuts out the faulty coil, binds the wire round the two ends of the commutator segments, and away it goes again. The machinery is not stopped for long. That has happened over and over again. I have some drum armatures, and I wish I had not, because breakdowns are always occurring with drum armatures in the ratio of 4 of the drum to 1 of the Gramme. If I have to buy a new motor for our kind of work I do not look for the one with the best name, but I go for one the parts of which are easy to get at if anything goes wrong, one which can be easily repaired. The haulage in a mine is very similar to tramway work. The generating plant and load are also very similar. We have several 200-horse-power Parsons steam turbines, and the load on them is very much like that for tramway work. I may tell you some of our experience with steam turbines. When we decided to install these at the end of 1895, colliery engineers scoffed at us and told us we were foolish to go in for such high-speed engines. Various travellers who came recommended their machines, and one said that belt-driving is the best. Others said it is better to have a high-speed engine coupled direct. I did not like that, because of the shock being transmitted direct to the moving parts of the engine. Other travellers said the steam turbine was the worst of all for that kind of work. But as there are no reciprocating parts there are no excessive stresses developed. That has been proved in our working.

Mr. Holiday. We have had them going night and day since 1896, and our total load is about 1,000 H.P. It is a load that comes on and off very quickly. People also warned us that we were getting a rather complicated machine which was so designed that our own fitters could not deal with it. We have four of them, and they have been running for five years perfectly. The only fault we have found is that the oil is sometimes inferior to sample, and of course the bearings get hot; but in a colliery, when that happens, you must go on if you can. You can pour water on the outside, and thus go on until the coal-winding ceases. All we have done where the bearings have worn down and stripped some of the turbine blades was to lift the cover of the turbine, cut the three or four damaged rows out with a hammer and chisel—there are 100 rows or more, so the loss of three or four does not matter much—put the cover on again, and at the end of the week re-blade it; and we find a colliery fitter is good enough for the work. Our experience with turbines is so satisfactory that we have constantly increased them, and we are expecting to put down 350-horse-power turbines. They are not bolted down to the foundation. With regard to the steam consumption, it is no worse than with most non-condensing generating plants, namely, 39 lbs. of steam per kilowatt per hour. We have had several tests with isolated boilers, and found it 39 to 40 pounds per kilowatt. That test was taken after the turbines had been running for two years. With regard to coal-cutting we have used a three-phase motor, and experimented first with it in 1897. Coal-cutting is the worst sort of work you can have for a motor. If it is a disc cutter, the coal comes down and stops the working by jamming the wheel. In such cases you often have to start off against not only a heavy load, but against an absolute fixture; you have to move the solid rock if you can. Another point is the excessive vibration, for you are not on foundations at all; you have the motors fixed on a machine which is dancing about all over the place. It is grinding away at the soft rock, and vibrates terribly. Even a three-phase type of motor is not perfect. The three-phase motor will stand moisture and coal-dust, but it is the vibration which tells on it. The maker's men are not careful enough in bringing the wires out of the slots. At the point where the wires are brought from the slots and turned up at the ends the insulation gives way just at the sharp corners owing to vibration, so I think the corners should be rounded. We have bent the wires down and put extra insulation in, and put them back in their places, and have had no further breakdown.

As to the starting, that was a great difficulty. Series motors are generally used in coal-cutting. With series motors, if the wheel is jammed quite fast, and the current is switched on with a 500-volt circuit, and if the attendant does not switch off immediately, the armature will be burned out quickly. It all depends on the seam that is being worked. If the coal is soft and does not come down much, the armature will not suffer much, but with a hard seam the cutter-wheel will often be jammed. One advantage we found with the polyphase motor was that when the machine was jammed and was switched on, there was a hum, but there was not the excessive current

which blows the fuses and burns the armatures of continuous-current motors. At the same time we found that there was a very considerable torque at the moment of switching on. We could see that from the effect on the coal-cutter, which jerked forward at the moment of switching on, and with the current still on it eased back. So we found that if we made a switch that would stand any amount of switching on and off, it always moved the wheel a little bit, and finally worked it free. We made a gas-tight switch which costs us 8s. complete, a box 12 inches long by 6 inches wide, with three contacts down each side and three sliding bridges. These switches have all parts interchangeable, and if anything goes wrong we have the spare parts ready, put them on and go on again with the work. After experimenting in this way for some time we tried a friction clutch, so as to allow the motors to get up speed before beginning to drive the cutter-wheel, but we have finally adopted a simpler arrangement. The motors are geared six to one on to a wheel which is free to make one revolution before moving the driving shaft, so that they make several revolutions before beginning to drive the cutting-wheel. When the man stops, he, by means of a reversing switch, runs the motors back to the starting point; then on starting forward again, the motors get up sufficient speed to start the wheel well. We had to put slip-rings on the motors at first, but we have now done away with them. The coal-cutter was the most severe test we had experienced. The result of our trials is that we are going to build a number of machines running with three-phase currents, and we use either a converter or a turbine alternator to drive them. Mr. Holiday.

Mr. E. Brown (*communicated*): In regard to *lighting*, I do not agree that arc lamps are suitable for the pit bottom, as there is not, as a rule, sufficient height to fix them so as not to be dazzling to the eyes, but prefer the ordinary 16-c.p. lamps, "scattered," so as to eliminate as much as possible the effects of shadows. The same remarks apply to the screens. Mr. Brown.

As to *generators*, I approve of ventilating spaces in armatures, and if they are blown through each day with a pair of hand-bellows no trouble will be found with dust. The cord binding, to hold down the armature wires, ought to be kept about half an inch from the commutator bars to allow the dust to escape while running, or when using the bellows, several breakdowns having been caused by binding close up to the commutator and so making the escape of dust impossible. Of course, spare parts such as armatures or field windings must be kept in a dry place, or they will be worse than useless when required.

In connection with the *switchboard*, it appears to be a good idea to have a megohmmeter to test the insulation resistance of the lines; hitherto the writer has only used the ordinary galvanometer when the machines are at rest.

Cables require in the shaft some protection, as pieces of coal dropping from the cage when the tubs are banked, and also, in winter, ice which has formed in the shaft walling, &c., are liable to pierce the insulation and cause a great deal of trouble. Some classes of water attack the lead covering of the cables, and at collieries where this

Mr. Brown. is the case lead-covered cables have been abandoned, the cables are put into grooves ploughed to suit them in a 2 inch × 11 inch plank and an inch board is screwed on to the front, the grooves are well tarred both before and after the cables are put in, and then the face board is screwed on.

As to *switch gear for motors*, it is important with shunt motors to have the shunt switch interlocking with the main switch, so that the shunt must be closed before the armature circuit can be closed. The usual resistance being used in the armature circuit together with a magnetic blow-out to prevent sparking at the last contact when opening the circuit, it is only necessary to break the shunt circuit when the motor is done with, and through a resistance as mentioned by the author. Motors must not be used where there is gas. They ought to be ventilated with fresh air; invariably there are ways and means of doing this, except in the case of coal-cutters at the face of the coal, which ought to be enclosed. No prudent man would think of working a motor, knowingly, in an explosive mixture; in the first place the safety lamps would go out, and work would be suspended until the ventilation was improved. All the same, motors and switches on coal-cutters working in seams where inflammable gas is given off should be enclosed. We have six 50 kw. motors, four pumping and two hauling, besides several smaller ones, and they all have Gramme armatures, and the most we have had is four coils burnt out at once (out of seventy-two in the whole armature). The motors are never left unattended, and it is easy to detect by smell as soon as a coil begins to burn. All our 50 kw. pumping motors are series-wound, and the 50 kw. hauling motors are compound-wound. One 25 kw. motor is shunt-wound, and is a very satisfactory machine. Cleanliness is the great secret of success in electrical transmission, given a proper training of the attendants. We have had as many as six coils on one armature cut out of circuit (when they have fused) by soldering strips across the commutator bars, and have gone on using the motor for some weeks. Carbon brushes are used on all our dynamos and motors; they wear away at the rate of about half an inch in six months' continuous running. Some of the motors run twenty-two hours per day at 600 volts.

With reference to Mr. Walker's paper, I agree with him that there are many difficulties yet to be overcome before electric miners' safety lamps are a practical and commercial success, and think that a lamp of, say, 1 c.p. should be aimed for; it should weigh not more than 3 lbs., and the battery should, preferably, be a secondary one.

It is quite necessary, even on the lamps used by the miners, to have some form of automatic device to indicate the presence of fire-damp in the air before the proportion of gas to air becomes dangerous; and it is *absolutely necessary* to have some more sensitive device on the lamps to be used by officials, whose duty it is specially to examine for gases such as CH_4 and CO_2. The gas-indicating apparatus of the Sussman Company, as described on page 836 by Mr. Walker, seems to be a step in the right direction, and if it can be made to indicate both CH_4 and CO_2, it will be an important addition to miners' electric safety lamps.

The Coal Mines Regulation Act forbids any person from taking matches into any mine where safety lamps are in use, so that if a lamp is accidentally extinguished it is of no use for a workman to open his lamp to light it and so commit a breach of the Act, unless he has previously committed a breach by taking matches into the mine with him, or opening a second lamp to light the extinguished lamp with, in which case the lead rivet by which the lamp is locked would be missing from two lamps when returned to the lamp-room and would so make detection sure. Many mines now have provided lighting stations as near to the faces as advisable where the lamps can be lighted electrically, without opening them, so saving a great deal of time and removing to a great extent the temptation to open them. This can now be done with any safety lamp without altering the lamp at all, but simply by putting in a new glass having a metallic spike or conductor riveted into a hole drilled in the glass, the spike projecting a little above the wick tube, but not touching it, the lamp bottom forming one terminal and the outer end of the spike the other. A primary battery with an induction coil is used. The system is patented, and acts well. Mr. Brown.

The writer agrees with Mr. Walker that it is important to have measuring instruments in circuit when charging secondary batteries; they are equivalent to the steam and water gauges of a boiler, as without them you are in the dark, and may at any time do much damage.

No doubt much time, patience, and money will yet have to be spent before electric miners' safety lamps are perfected, and if the cost can be brought down to, say, 4d. per lamp per week, and a light equal to 1 c.p. given to the collier, he ought to surrender half of the amount of extra tonnage rate given him when safety lamps were substituted for candles, which is 2d. per ton—therefore a reduction of 1d. per ton would warrant the use of the more costly electric lamps, to say nothing of his own increased safety. It will be a difficult matter to convince him, but the fact is all the same.

The writer has ignited ordinary illuminating gas by a spark from four B-size Obach dry cells in series for signalling purposes.

Mr. L. W. DE GRAVE (*communicated*): Mr. Ravenshaw's paper opens out an enormous field for discussion, referring as it does to the application of electricity to one of the largest industries of the country, and one in which the engineering difficulties are the greater in that the conditions are always liable to variations without warning. Mr. de Grave.

Power transmission in coal-pits practically resolves itself into the consideration of the questions of cables and explosive mixtures. The various systems of cables have, of course, their own adherents. Some nine years ago, when the use of 500 volts was becoming general for pit work, I saw that accidents more or less serious would occur unless some improved cable system were employed. The system I designed to prevent these accidents consists of a copper inner conductor heavily insulated, and a bare galvanised-iron wire outer of the same carrying capacity as the inner, this being practically a single cable armoured, but having a considerable bed between the dielectric and return conductor.

Mr. de Grave.

This cable is run down the shaft in a galvanised-iron pipe half an inch larger in diameter than the cable, the natural twist in which tends to bind on the pipe and thus support its own weight, a cast-iron box being provided (as an auxiliary) containing a pair of clamps which grip the cable. The pipe is continued some few yards into the "inset," the cable there entering a cast-iron junction box, the inner conductors being clamped together (air insulation), and the outer bare conductor being clamped up in a packing gland with lead wire packing, thus completing the circuit through the box. Along main roads, cross-gates, and gate roads, the cable is supported on a piece of galvanised-iron wire, one end coiled five times round the cable, the other end being hung over a nail driven into a prop, this arrangement being to allow the cable to fall to the ground if caught by a fall of roof. At all junctions and cross-gates junction boxes and, if required, single-pole switches in cast-iron boxes are fixed. Trailing cables for coal-cutters are double insulated concentric, and having of necessity to be flexible metallic armouring, would be too light to be of service, consequently they are sheathed with leather and other mechanical covering. This class of cable with bare return has advantages over ordinary armoured single cables: there being what is practically only one cable to run and maintain, all shock risk is eliminated, and, if made to a proper specification, no leakage or, what is really the same thing in a concentric cable, no short circuits will occur. This system has stood the test of time and every condition of pit work.

The most important point raised by this paper is that of "gas," and the advisability of enclosing motors, &c. In most seams of coal small percentages of gas can be found in the "return"; but leaving out of account for the present machines on the coal face, and dealing with, say, a haulage or pumping plant "inbye," there is nothing to prevent the plant being put on the "intake" where a place free from gas can be found or made; this in itself removes the necessity of enclosing, even if the enclosing of motors, &c., against gas were possible.

Apart from hermetically sealing (a condition which, as Mr. Ravenshaw admits, cannot exist), the motor or starting switch gets hot, the air expands and gets away somewhere, through the bearings or even along the core of the cable. The motor cools and draws in air or "gas," the first spark of sufficiently high temperature ignites the mixture, and, as a result, there may be anything from a ruined motor case to a wrecked pit. If a protection from gas is required it should take the form not of a gas-tight joint, but a flame-tight joint, which will let the gas in but will not let the flame out, this being the principle of the safety lamp. A gap of $\frac{1}{32}$ inch, $\frac{3}{8}$ inch in length, will cool any flame from an explosive mixture; there must, of course, be an area of joint in proportion to the cubic contents of the case. Such flame-tight joints I have made and worked in pits for years, tested them in explosive mixtures at high velocities, and seen the gas burning inside without communicating flame to the outside.

As to motors on the coal face for coal-cutting: Mr. Ravenshaw says these are always enclosed and series-wound. Here we must agree to differ, as out of the many electric coal-cutters I have at work (in

practically every coal basin in the country), not one is enclosed and not one is series-wound. Against gas I should never dream of enclosing; against dust I consider it inadvisable, as the cooling is bound to bring dust in, and there is the copper and carbon dust from inside to contend with. An enclosed motor in a pit generally runs as long as it will turn round without being cleaned or opened, whereas with an open motor the machine man knows it is dirty and cleans it. Mr. de Grave.

We electrical engineers who are also mining engineers know that if there is gas in explosive quantities electricity is not to be used on the coal face. What we do is to find a suitable place on the intake in some central position as close as convenient to the face, put in an electric motor, drive an air compressor, and employ air-power coal-cutters; we lose about an extra 20 to 25 per cent., but at the worst get 50 per cent. compared with 20 to 25 per cent. when the air is compressed on the surface. The alternative to this is to enclose the motors, &c., and put on inside the case an air pressure of, say, 10 lbs. through pipes from a fresh-air supply and maintain it night and day; this arrangement is an excellent one for chemical works, &c., but for ordinary colliery work it is unsuitable, except under somewhat exceptional conditions. When all is said and done, however, the objection to enclosing is the feeling it gives of security which does not exist; this in itself is a very serious danger.

Referring to the series-winding of coal-cutter motors, the object is, of course, maximum torque; but a properly designed shunt motor with a strong field will give all the starting torque a coal-cutter ever requires, and has the advantage that it can be run with the feed gear out of action. The objection to a series-winding is the increase of speed when the feed gear is thrown out (necessitating switching off). The answer one sometimes gets to this is that the resistance of the gearing keeps the speed within 10 to 20 per cent. of the normal, which does not say much for the mechanical part of the machine.

Mr. Ravenshaw makes some very sweeping condemnations of ring armatures; and whilst praising the drum for "short circuiting," omits to mention that a ring is, from its very construction both mechanically and electrically, less liable to break down than a drum.

My previous remarks show that I attach but little importance to sparking in connection with gas, so that a burnt-out coil, or broken connection, does not appeal to me as against a ring armature; but if my armatures were in the habit of burning out, &c., I should certainly prefer a ring, for the reason that if, say, a coil burnt out or short-circuited at 10 a.m., the mere fact of being able to keep going to the end of the shift (where the output of the pit depended on the motor being kept going) would from the point of view of cost outweigh everything else, as the cost of a new motor would be nothing compared with loss of output. In coal-cutters and most other machinery except haulage an hour's stop to change an armature would hardly count in the week's work. The damage done to an armature and commutator running for a few hours with a bad coil is comparatively slight if anything like a massive commutator is employed.

Alternate currents (multiphase) have not been very generally

Mr. de Grave. adopted up to the present. I have some large units, but their superiority over continuous currents has yet to be shown. Speed regulation is a difficulty, the cable question is not by any means settled, and the extra risk from shock which practically necessitates the reduction of pressure to 200 volts rather discounts the advantages.

Several fatal accidents have recently occurred in pits from shock, but these are perhaps beyond the scope of the present discussion. Referring to the examples given at the end, I notice Mr. Ravenshaw refers to these as having occurred during the last ten years, and this probably accounts for the majority of them being due to what is to-day known to be bad design.

Mr. Hall. Mr. HENRY HALL (*communicated*): I have read Mr. Sydney Walker's interesting paper. It is true little progress has been made towards furnishing the mines with a practical, portable electric lamp. Such a lamp would be a great boon to the workers in mines, especially to hauliers and other hands who have a good deal of moving about in the course of their work, and for such purposes it is, I think, unnecessary that the lamp should be fitted with any gas-testing apparatus.

Cannot electricians contrive a lamp to be fixed to the cap after the plan adopted by the miners in Scotland and France, with the small open light. For the hauliers to have their hands free would compensate for any additional cost.

Mr. Peake. Mr. H. C. PEAKE (*communicated*): The former paper is a very practical one, and there is very little that I can say in criticising it. The writer seems to come to the same conclusion that I have, namely, that in the past electrical appliances have been too weak, resulting in breakdowns; these have made many people condemn electricity. If machines had been made stronger at first, and better adapted to the work they had to perform, there would have been a much more extended use of electricity at the present time than there is.

There are one or two points on which I don't quite agree with the author. In most pits solder can be used on the main roads, and it is better and cheaper than using "Junction" boxes. Our experience is that totally enclosed machines are better, as they are not liable to get so covered with dust and dirt as are the open machines. For pumping and hauling, in fact, for any work which is variable, compound motors are preferable to any others, as their speed is more regular than that of series machines. I do not think that shunt-wound motors should be used for pit work.

Mr. Barnes. Mr. J. S. BARNES (*communicated*): In the first place I must congratulate the Institution on having a paper brought before it dealing with so broad a subject and one in which there is plenty of room for improvement and new applications. The paper of Mr. H. Ravenshaw deals with electrical transmission in coal-mines on very broad lines, and opens up a vast field for discussion. No doubt electrical energy, both for lighting and power purposes, is becoming recognised as reliable and economical, but in many instances the managers and directors will have to be converted from the old to the new school before electrical energy will be used universally for mining purposes, and before they feel assured that they are to gain materially by the substitution of

electrical appliances for old, inefficient machinery and methods. I do not think the question of cost will be considered by them. There are very few collieries which employ voltages higher than 110 for lighting, and only modern and deep collieries have adopted 220 volts, the 220 volts circuits giving more trouble by leakage and electrolysis, and danger from shocks for the most part counterbalances any saving in copper in the mains. In shafts of 500 yards or deeper no doubt the 220 volts would be used advantageously, and would secure economy on cost of mains, but for shallow mines the 110 volts system will hold its own. It is very seldom that more than 500 volts are used for transmission purposes, or that either the three-wire system or accumulators are installed. Mr. Barnes.

Enclosed arc-lamps used in screen, pit-heads, and banks, have the advantage of not allowing hot fragments of carbon to cause ignition of coal-dust or inflammable materials, but to my mind no arc-lamps should be used in pit-bottoms, especially in dusty or fiery mines and in the downcast pit-bottoms. In this case, were there a large outburst of gas, which, as a rule, reverses the direction of the air-current, a disastrous explosion might take place. The average colliery engineer who is responsible for examining boilers and all machinery is very reluctant to take over the working of high-pressure steam apparatus and very hard to convince about its economy, but all modern collieries are practically resorting to high steam pressures. I do not know of any winding engine being used for driving dynamos, simply from the fact that it is not suitable, as it is stopped, started, and reversed hundreds of times in a working day; why Mr. Ravenshaw should allude to winding engines at all in his paper I fail to recognise. Sometimes the fan engine is used for driving electrical machinery, but in many cases this is not desirable. First-class high-speed vertical engines are not likely to make rapid progress for colliery work, as the manager will not pay qualified mechanics who understand them. The ordinary colliery engineer and mechanic naturally prefers to adopt and look after the slow-speed horizontal engine, which it is easy for him to repair and understand.

Internal ventilated air-spaces in dynamos and motors certainly harbour dust, but I see no serious disadvantage in this if the dynamo attendant blows through the spaces with a pair of bellows daily. Some collieries keep the space armatures in a cold and damp store-room; but this is wrong; they should be kept in the dynamo-room which is generally of a warm and even temperature.

In tail- and main-and-tail-rope systems of haulage the load for every train of corves (pit-waggons) is practically constant with respect to the train itself, but the load on the motors varies considerably by depending on the various gradients along the haulage road, and the number of starting and stopping stations of the train, and the number of corves left or taken from any particular station. In endless-rope haulage, if the loaded corves are put on to the wire-rope at regular distance and at constant intervals, as they are taken off at the pit-bottom, and the same system is resorted to with the empty corves, the load on the motor is practically constant; but this ideal is

Mr. Barnes. impossible unless there is always a surplus of standing full corves at stations along the haulage road together with a surplus of empty corves standing at the pit-bottom ready for connecting to the wire-rope. In any case the fluctuation of load on the motors is unavoidable, but it is not limited to quick and sudden falling off or overloading, as the wire-rope generally only travels at about three miles an hour against the tail- and main-and-tail-rope haulage systems travelling about ten to twelve miles an hour. Should the corves suddenly drop off the rails and become jammed, there is a very severe overload with the latter two systems of haulage, and this throws sudden overloads on to the motors and wire-rope; but in most cases, before much damage can be done to the motors, the rope will break, owing to the sudden stress caused by its relatively high velocity and to the corves coming in contact with resistance. Then retardation results, or the motor fuses will blow if any corves fall off the rails. In the endless haulage system there is not such a sudden overloading of the motors; the motors will of course be overloaded, but not so suddenly.

Switch-boards at collieries should be constructed of incombustible materials as far as posssible, and be subject to Board of Trade regulations with respect to the distance at the back of board, etc. One often finds instruments and switches mounted directly on a base of wood fastened immediately against the wall with no accessible room behind them. Wattmeters and earth lamps would be very useful on colliery switch-boards, but they are conspicuous by their absence at nearly all collieries. Cables in damp and wet places should have a moisture-resisting substance for their insulation, and should be lead-covered. In situations where the temperature is constantly fluctuating, bitumen insulation is liable to crack and cause leakage. Cables should never be installed in the upcast shaft, not only on account of the important reasons given by Mr. Ravenshaw, but also because, should there be an earth on one side of the system (say the positive) anywhere on the network, and should a fault develop on the other side of the system (*i.e.*, the negative) in the shaft and then cause sparks, a fire in the shaft would probably be the result. Should any explosive gases be passing up the shaft at the time, a disastrous explosion might take place.

In reference to breaking the shunt coils of the motors without any resistance in circuit, not only would disruptive sparking and straining of the insulation take place, as pointed out by Mr. Ravenshaw, but the motor would lose its magnetic field, together with its load, and hence must short circuit and eventually burn out the armature.

Evidence as yet has not come to hand of sparking brushes causing an explosion of gas in mines. However, as the electrophorus will ignite the gas from an ordinary gas jet, it is only reasonable to assume that the intense sparks, emitted from the brushes, would ignite gas in the mine, and no doubt multiphase motors will eventually supersede the continuous-current motors not only from the absence of sparking in them, but also on account of the better mechanical results in dealing with overloads, etc.

Motors for pump and haulage work in damp and wet places in

mines should not be coupled to the pumps or haulage apparatus direct through spur and metallic gearing, because the attendant may receive a severe and dangerous shock. In any case the stress and strain is more severe on the machinery itself, due to its rigidity; and rope-driving should be resorted to, because there is more flexibility, and it takes up the sudden stress of the load. Mr. Barnes.

Coal-cutting is a very severe and trying test for a motor, and to my mind the multiphase is preferable to the continuous-current motor for this class of work. I have a case in mind where at least one or two armatures are burnt out weekly, due to sudden overload by the cutters getting jammed, and I consider that in the future there is a great field for multiphase motors for this class of work. The author of the paper has entirely left out of consideration the uses of electricity in the operations of mine-sinking, and coal-washing, and in replacing isolated small steam-wasting engines by motors. Of course these are subjects which are not connected with work below ground in the coal-mine, but nevertheless are of importance in connection with the works at the surface. The points raised by Mr. Ravenshaw numbered alphabetically are to my mind common occurrences, but where technical knowledge is possessed by the electrician at the collieries, they are not likely to occur.

Mr. W. MAURICE (*communicated*): Mr. Walker is well known to have devoted considerable time and energy towards the solution of the problems involved in the production of a satisfactory portable electric lamp, and it is therefore advantageous to have from him so comprehensive a contribution on the subject. Mr. Maurice.

In the design of "gas" indicators for electric hand lamps I do not see that anything further is necessary than to provide means of showing the presence of a suffocatingly dangerous volume of "gas." Normal quantities of gas would be detected by the officials in charge of the mine, who rarely leave any working place uninspected for a longer period than two hours. It is doubtful if extremely sensitive "gas" testers are of much real value, for mine "gas" usually consists of a mixture of methane (CH_4), and other of the homologous (paraffin) series of the hydro-carbons, with various other gases—analysis yielding different results in different mines. Sulphuretted hydrogen requires no other tester than a man's sense of smell. Carbonic acid gas is rarely found in appreciable volume except under circumstances when its probable presence would be foreseen, and provision made for dealing with it. The same may, in a practical sense, be said of carbon monoxide, since such quantities as might conceivably be produced in ordinary operations would be swept away by the ventilating current before any injury would be likely to result from its presence. CO is sometimes tested for in mines by means of palladium chloride, into a solution of which a piece of white filter paper is dipped, the presence of CO being indicated on the paper by varying degrees of discoloration, according to the percentage present in the atmosphere.

I quite agree with Mr. Walker that there would be fewer accidents from falls of roof and side if it were practicable substantially to increase the illumination of all working places in mines. But I doubt it cannot

Mr. Maurice. be said that there is now a lamp in the market which fulfils necessary conditions—entirely regardless of its initial or upkeep cost. I have at one time or another during the last ten years tried every secondary cell lamp described by Mr. Walker, with the exception of Sussman's most recent pattern, and though several are excellently made, and most useful for some purposes, they do not meet the every-day exigencies of mine-working. Most of them can be taken in pieces by means of a pocket-knife or a nail; most of them are so heavy as to induce in the workman a disposition to neglect his periodical inspections of the working place; and all, sooner or later, "go out" at an inconvenient time. With some it is impossible to examine the roof of the mine properly; with others, it is equally impossible to inspect the floor. For the purpose of making personal examinations, I find the most satisfactory combination in the Bristol pattern accumulator with detachable lamp in bull's-eye case. With the cells strapped to the waist and the lamp hung on coat lapel or carried in the hand, the most minute inspection of roadways, etc., can be made with ease.

Mr. Walker does well in attempting to exorcise the "spark" fiend. It has proved a most powerful influence against the introduction of electrical apparatus into coal-mines, though there are comparatively few in which an occasional spark could be seriously supposed to be a source of danger.

Mr. Wilkinson. Mr. H. D. WILKINSON (*communicated*): Mr. Ravenshaw has pointed out the extremely trying conditions under which electrically-driven coal-cutters are required to work, and I am sure no one familiar with them will say that he has overstated the case. Notwithstanding the severe conditions, the economies to be effected in coal-cutting by mechanical means over hand labour are so considerable that the use of these machines has lately become greatly extended and their design improved. In long-wall mining it is possible now to undercut to a depth of 7 feet by electrically-driven cutters, thus saving the large amount of round coal which would otherwise be broken up in holeing out by hand, and enabling the block to fall by its own weight without blasting. Mr. Ravenshaw makes no more than a cursory reference in his paper to the employment of polyphase motors for cutters, but I think this side of the question may assume too important a bearing to be passed over without further reference while the subject is under discussion.

Conditions may exist which favour the polyphase system even when each mine is supplied from its own generating station at the pit-bank and the transmission is direct from generators to motors. But when it is desirable to supply several neighbouring mines from one generating station at a central mine, and for reasons connected with economy and regulation power is distributed over several miles by a high-tension polyphase system, considerable saving may be effected and simplicity in working gained by dispensing with intermediate converting machinery and adopting multiphase motors for every purpose.

Having carefully watched the performance of coal-cutters at the coal face underground in different mines, both with direct-current and three-phase motors, it is clear to me that not only are polyphase motors practicable for coal-cutters, but, with a not too narrow seam, they are

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preferable to direct-current motors. At Messrs. Pope & Pearson's colliery, Normanton, two 10 H.P. (nominal) three-phase motors are fitted to a cutter, one at each end, and both geared to the cutter-wheel through reducing gear. The stators of the two motors are connected in parallel, and the rotors are self-contained, having no slip-rings or external resistance. Current is generated at 600 volts, with about 550 volts at the motors, and the starting switch on the cutter puts the full voltage on to the stator. Reversing is provided for in the same switch in the usual way by reversing two or three line wires. One main switch is also provided independent of the reversing switch, but no further means of breaking circuit is necessary at the motor, the usual three-pole switch and fuses being provided at the gate junction box some fifty yards away.

A voltage equal to anything that is used with direct current can be used with polyphase motors without as much, if any, risk of shock, because from their construction there are no exposed parts. Their size is somewhat larger than direct-current motors for the same power, but this is only a question of suitability to the seams being worked. From the mechanical severity of the work in coal-cutting and the small clearance between rotor and stator the bushes require renewing rather more frequently than in more ordinary work, but this is by no means a serious item, and no harm results to any of the windings even if bushes are not renewed in time to prevent touching. The initial difficulties in re-starting when the cutter-wheel is absolutely jammed have been well put before us in the discussion by Mr. Holliday. The initial torque, which in a direct-current series motor can be made about four times the full-load torque, by large increase of current can in the polyphase motor be made as much as twice or two-and-a-half times the full-load torque at starting from rest; but, as Mr. Holliday explained, a better means has been devised for re-starting under these conditions, namely, provision in the gearing for a certain amount of backlash. By this means, when the cutter-wheel is jammed, the motors and gearing can be got away from the wheel by reversing, and then upon re-starting, the motors can gain several revolutions before they come up to the work, thus enabling them to develop sufficient power to shift the wheel and continue the work. This method was, I believe, also simultaneously and independently devised by the Diamond Coal-Cutter Company, of Normanton, Yorkshire, who have introduced many improvements in coal-cutters, and in connection with the General Electric Company of London and Manchester have worked these machines successfully with three-phase motors.

I understood Mr. Kapp, in his remarks, to lay stress on the greater suitability of direct-current motors for hauling, where large initial torque and speed regulation were required; but I presume he applies this more particularly to large electric winding machines for hoisting in a shaft, as, indeed, the example he gives of a 1,000 KW. plant leads one to suppose. Otherwise, for comparatively small hauling machines up to 50 or 60 H.P., such as are used at the pit-bottom for hauling tubs out of the mine on the level, the polyphase motor appears to me quite as suitable as the direct-current. For such work there is no necessity for

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a rapid acceleration of the tubs from rest, and the usual interlocked switch lever for reversing and varying speed by resistance in the rotor circuit answers exceedingly well for this kind of work.

Mr. Sayers.

Mr. W. B. SAYERS (*communicated*): I was greatly interested in Mr. Ravenshaw's paper and in the discussion which followed it. With regard to the paragraphs on "Switch Gear for Motors" and "Motor Starting Switches," Mr. Kapp anticipated me by inquiring why Mr. Ravenshaw does not use the method of connecting up a starting resistance in which the armature, shunt coils, and starting resistance are coupled up in series forming a closed circuit, and which obviates any difficulty from inductive effects of the shunt, both as regards sparking and danger to insulation. I am constantly meeting with cases where other arrangements have been adopted and have given trouble, and invariably change them to the one described with perfectly satisfactory results.

One very important point in favour of it is that a broken connection immediately asserts itself, whereas a break in a non-inductive resistance connected in parallel with the shunt may remain undiscovered or may be neglected until damage has been done. Liquid resistances, as made, give trouble in my experience owing to steam, and salt or soda crystals, destroying the insulation; but assuming that a satisfactory design could be made, it is a serious disadvantage that in the case of shunt motors the closed circuit method of connecting with starting resistance cannot be used.

As regards the use of a non-inductive resistance in parallel with series coils, I would point out that if anything like the same proportions were adopted as Mr. Ravenshaw recommends for shunt coils, namely, that the resistance should be equal to twice that of the coils, there would be serious interference with the characteristic of the motor unless the coils were designed to be shunted with such a resistance.

The waste of energy which would result with a resistance coupled permanently in parallel with the series coils is, I think, not warranted; either the resistance should be coupled in by the switch just before breaking circuit, or the switch contacts and length of break, and the insulation of the coils should be designed to stand the extra sparking and stresses. The extra stresses on insulation are, of course, small in the case of a series coil when compared with those caused by the breaking of a shunt circuit. I agree with Mr. Ravenshaw that it is better to have starting resistances large enough to be used for regulating purposes without danger. The difficulties with liquid resistances are, of course, greatly increased when they are used in this way, owing to the steam generated.

With regard to the use of compound motors I do not follow Mr. Ravenshaw's argument; if the shunt winding of a motor has been properly designed, the motor will run a little slow when started up cold, and will gradually creep up to its normal speed as the shunt heats up. If the shunt gets too hot there may be worse results than the mere increase of speed of the motor. The objections to compounding where it can be avoided are increase of cost and the necessity of using finer wire on the shunt than would otherwise be

required. The change of speed with heating will take place even in a compound motor, though to a slightly less extent than in a simple shunt motor; and it may be avoided where objectionable by having a rheostat in the shunt circuit which is cut out as the temperature of shunt rises. Mr. Sayers.

As regards the use of Gramme winding for armatures, and referring specially to the remarks of Mr. Holliday, it is easy to understand that mining engineers should prefer an armature in which they can readily cut out a faulty coil and start to work again without much loss of time, so long as their experience warrants them in holding the view that electric motors must be subject to such faults at comparatively frequent intervals.

But this view is not warranted if the best class of drum armatures with barrel end windings are considered; this type of armature is susceptible of far better mechanical design than a Gramme-wound armature, and the breakage of commutator connections and occasional short-circuiting of coils is a thing of the past as regards such armatures.

I was lately called in to report on the cause of failures to a number of motors in use on electric cranes in a stone quarry. The armatures in four motors had each of them one or more coils cut out of circuit, and the commutator sectors bridged in the manner referred to by Mr. Holliday. The owners of the quarry objected strongly to the necessity for making such repairs, and I entirely agreed with them, and recommended that the motors should be fitted with drum armatures of an improved mechanical design; and from other experience I have no doubt that although the strain to which the armatures referred is exceptionally severe, owing to the nature of the work they have to do, that the change will be a complete remedy.

Where there are a number of motors of the same size and type with interchangeable armatures the provision of one spare armature is usually sufficient to avoid risk of serious interruption to the work in case of anything going wrong.

Mr. A. T. Snell (*communicated*): The applications of electricity to coal-mines are chiefly interesting to the colliery engineer and those engaged in the design and supply of special machinery. The subject is studied but little by electrical engineers in general, and hence probably the rarity of occasions on which papers bearing thereon are read before the Institution of Electrical Engineers. Mr. H. Ravenshaw is to be congratulated on his brief but suggestive paper. No one is better qualified by past experience and present practice to deal with the whole question, and his *résumé* of work done and progress made during the past ten years is specially opportune and valuable. Mr. Snell.

As one of the first workers in the same field, since my first experience dates back to the eighties, it is particularly interesting to compare results with my able friend. Looking casually through the second edition of "Electric Motive Power," and comparing point for point with Mr. Ravenshaw's paper, I am much pleased to find how closely our general conclusions agree. Indeed, it would appear that the lines on which electric power with continuous current is most

Mr. Snell. safely and economically applied to coal-mining have reached a fairly defined state. Improvements in details are of course possible and desirable all along the line, but no colliery proprietor need now hesitate to sink capital in electric power because the special plant is immature or untried.

Electric lighting for pit bank and shaft bottom is now the rule. Pumps, both main and dip, are frequently worked electrically, and the advantages of electric haulage are becoming more and more apparent. Electric coal-cutting has also received a marked impetus during the last few years, Messrs. J. Davis & Son and Messrs. Clarke, Stevenson & Co. being especially successful with their respective plants. As for cables, I agree with the author as to the good qualities of Messrs. Callender's armoured vulcanised bituminous cables for shaft and other exposed positions. I join issue, however, respecting the author's preference for drum armatures. I have found gramme rings to give less trouble from "burning out" and to be more readily repaired *in situ*, which is a most important matter in colliery work.

The slow introduction of polyphase machinery into British mines requires explanation. That it is not due to inherent defects or unsuitableness in the special plant I am fully convinced, and I repeat here what I stated eight years ago, that[1] "the future of electric work in mines lies with the polyphase systems."

The author says he has not applied multiphase motors in mining work, presumably from necessity and not from choice. It is only during the last few years that this type of motor has been manufactured in England, and thus given confidence to those responsible for their recommendation. Now, the General Electric Company have supplied from their Manchester works an "all British" three-phase coal-cutter to one of Messrs. Pope & Pearson's pits, and Messrs. J. Davis & Son have a three-phase pumping plant (of American design, I believe) at Ackton Hall Colliery. Both of these, I am informed by Mr. H. D. Wilkinson, who inspected them last month, are doing excellent work. These small ventures represent, I hope, a new departure, and are the heralds of an extensive application of polyphase motors.

I am in sympathy with the author as to the amount of bad or unsuitable work to be found in colliery installations. Indeed, it says much for the "high order of intelligence found among those in responsible positions in collieries," but more for the safety of electric power, that so much has been successfully accomplished. I look for rapid progress in the near future.

Mr. Sydney F. Walker's paper on miners' electric safety lamps raises an important issue with which I have had no recent experience. Personally I tried in the early nineties most of the hand-lamps then exploited, but found all to be either heavy, weak in mechanical details, or difficult to charge quickly and completely, and all too costly in upkeep. The author does not appear to offer any definite solution of the problem, although he indicates the lines on which he thinks a suitable lamp might be evolved with a primary battery. My own experience with primary batteries has not been a happy one, and I do

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Mr. M. O'Gorman (*communicated*): There are several points of detail in Mr. Ravenshaw's paper which call for remark. He points out certain primitive methods in use in mines, and it is certainly to be hoped that no legislation will be put in force against these primitive methods which are the pioneers of sound engineering. The Workmen's Compensation Act alone is sufficient to make employers keenly alive to the importance of adequate safeguards. Mr. O'Gorman.

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It would have been interesting if detailed experiments of electrically driven winding engines had formed part of the paper, because these are comparatively unknown, and the reasonable certainty of their satisfactory operation is most important for central power distributions to collieries.

Mr. Ravenshaw's testimony in favour of bitumen cables is noteworthy. Presumably they are cheaper than rubber and lighter than lead-covered. But this by no means settles the matter, witness Mr. Holliday's most interesting communication on the use of lightly insulated, unarmoured slung cables. I cannot but think that if insulated cables are to be used, concentrics are better, cheaper, and equally reliable; leakage usually occurs from the outer and gives warning of a fault which might stop the work. In wet places they do not suffer from porosity of the negative, and they take up less room in the downcast shaft. I have laid and jointed lead-covered concentrics with complete satisfaction, so that the above is not a purely speculative statement. In every shaft temperature variations cause considerable difficulties with cables, and it is not always possible to use the downcast shaft. With fibre cables the dielectric flows downwards, and the fibre of the cable gets dry at the top. Each increase of temperature causes an expansion of the impregnating fluid to occur downwards. In practice almost complete dryness of portions of the cable seems to do no harm whatever for pressures up to 500 volts, except when the dry portion has to be cut for jointing or repairs. It is then exceptionally hydroscopic, and water may get in at the upper end and flow right down the cable, ruining the whole of it.

If after five or six years Mr. Ravenshaw finds that there is no viscous or other flow of bitumen, it certainly has an advantage in this matter; but the use of single cables individually armoured must increase the self-induction of the circuit, and therefore aggravate the viciousness of sparking. The use of steel tubes such as simplex, unless it be made

Mr. O'Gorman.

electrically continuous, is, I think, not advisable, in spite of Mr. Ravenshaw's favourable verdict. The supports of the simplex under ground are liable to move, and if the tubing has at any terminal become connected to either pole, the likelihood of a spark between two lengths of tube is considerable, and this spark may occur although the insulation of both poles to earth is perfectly good, because the enamel on the tubing at the point of support frequently gives it an apparently satisfactory insulation.

The President.

The PRESIDENT: I will ask Mr. Ravenshaw and Mr. Walker to give their replies at the next meeting.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Associate Members:

Arthur George Cooke, M.A.	Herrmann Oskar Eurich.

William Thomas Leeming.

Associates:

John Daniel Dyson.	Albert Edward Loos.
Richard John Montague Holmes.	Arthur Norris Robinson.
Albert Henry Hunt.	Samuel Robinson.
William Richard Kelsey.	Oscar Fridolf Alexander Sandberg.

Students:

Richard Charles Caldbeck.	Charles William Dilks Peel.
John Ridge Hewett.	George Wigram Stewart.
Robert Valentine Kemp.	Hans Müller Stich.

James Percy Winn.

The Three Hundred and Sixty-third Ordinary General Meeting was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 18th, 1901, Professor JOHN PERRY, F.R.S., President, in the chair.

The minutes of the Ordinary General Meeting held on Thursday, March 28th, were read and confirmed.

The names of new candidates for election were announced, and it was ordered that they should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Members—

John Powell Edwards. | Alexander S. Garfield.

From the class of Associates to that of Associate Members—

William D. Duddell.

From the class of Students to that of Associates—

Arthur B. H. Cope. | Alfred S. Esslemont.
John F. Henderson.

Messrs. J. S. Fairfax and E. A. Howell were appointed scrutineers of the ballot for the election of new members.

Donations to the Library and to the Building Fund were announced as having been received since the last meeting :—To the *Library*, from D. Van Nostrand Company, Mr. C. H. Wordingham, Member ; to the *Building Fund*, from Messrs. W. R. Rawlings, E. M. Malek, Herbert Nash, A. G. Seaman, Hans Stich, J. Grant, W. R. Wynne, H. J. Gridley, and F. O. Hunt, to whom the thanks of the meeting were duly accorded.

The PRESIDENT announced that the Council of the Society of Arts had arranged for a course of "Howard" Lectures, on Polyphase Electric Working, by Mr. A. C.

Eborall, and had kindly placed a certain number of tickets for the course at the disposal of the Institution. He further stated that these tickets would be issued to members in the order of application.

REPLIES TO THE DISCUSSION ON THE PAPERS ENTITLED:

"Electrical Miners' Safety Lamps," by S. F. Walker, Member.

"Some Notes on the Electrical Transmission of Power in Coal Mines," by H. W. Ravenshaw.

Mr. Walker. Mr. S. F. WALKER, in reply, said: Mr. President and Gentlemen—I am in the pleasing position of having very little to reply to. My remarks apparently met the approval in the main of those gentlemen who were kind enough to take part in the discussion. I am asked to correct a misapprehension that appears to have taken place with regard to the gas detecting apparatus that was shown at the last meeting. The apparatus is not the Sussman Company's apparatus; it is a patent of Mr. Prested's. It acts on a totally different principle. The Sussman apparatus acts on the well-known principle of the impingement of the light carburetted hydrogen gas upon finely divided platinum or paladium causing heat, which expands a column of mercury, making an electric contact. The Prested apparatus acts upon the equally well-known principle of the diffusion of gases. A certain quantity of the ordinary atmosphere of the mines is enclosed in a porous chamber, and when the light carburetted hydrogen gas rushes in it works a contact, closing an electrical circuit which sets the lamp alight. I hope I have made that clear. Professor Foster made one or two remarks which I will deal with very briefly. I quite agree with him that if coal-cutting machines were universally applied—as they will have to be, I feel confident, if this country is to hold its own with America and the Continent—the man, instead of having to spend his eight hours in a confined position using the whole of his muscular effort, will merely have to attend to a machine, and will then possibly not mind carrying into his working place a pound or two more in the shape of his lamp, and I hope that will come about. Then Professor Foster objected to my statement as to the locking of the safety lamps. Roughly there are three forms of locks in use in the present forms of safety lamps. One is practically no lock at all; it is merely a set screw. Another is the lead rivet which Professor Foster referred to, which is stamped in the lamp-room, and which a man can open if he likes, but he is afraid to do so because he is afraid of the police court afterwards. If a man did open his lamp and an explosion followed, the police court would not be of much service to anybody afterwards. I am assured by an experienced colliery manager also that the rivet can be worked with a penknife so as to be opened without showing it. Then the other one, and the most successful, is the magnetic lock. A small iron plunger fits into a recess made for it, and it is kept there by a spring, and can only be withdrawn by a magnet. That is not perfect, but it is the best of the lot. The point

Mr. Walker

that I wanted to make in my paper, and the point I wish to make now, is that all of these can be opened. A magnetic lock is the most difficult to open, but even it can be opened, and if it is opened, and if any lamp is opened, the consequences may be disastrous. On the other hand, if a miner opens the electric lamp the only thing he does is to put his light out. The difference is the same as between the man who has matches in his pocket and the man who has not. If a man has matches in his pocket he may use them ; if he has not matches in his pocket he cannot. Then Professor Foster also mentioned the point of carbonic oxide. He said that carbonic oxide was only found where there was combustion. I thought I had made it clear that you always have carbonic oxide after an explosion. When you have an explosion you also have following the explosion, sometimes as the cause of the explosion, the ignition of a large quantity of coal-dust which is lying about the mine. You do not have perfect combustion with the coal-dust, but the first stage of combustion, the combination of the one atom of oxygen with the one atom of carbon, and you have this deadly carbonic oxide formed. The first thing which happens after an explosion is that an exploring party goes into the mine and endeavours to rescue whoever may be left alive, and it is of the very utmost importance not only that carbonic acid shall be found, which the ordinary lamp will indicate by going out, but also that carbonic oxide shall be indicated, and there is no mining lamp at present which indicates carbonic oxide, so that the exploring party may be in carbonic oxide and not know it, and may be getting a deadly dose of it. It appears to me that a gas detecting apparatus which will also show carbonic oxide, whether it is attached to an electric lamp or whether it is taken independently, will be of immense service after an explosion. I think those remarks also deal with what Mr. Atkinson, the Inspector of Mines, stated. Mr. Mitcheson objected to my statement as to the cost of the upkeep of the Sussman lamp. I am in the position since the last meeting of being able to put corroborative evidence before the present meeting. Since the last meeting of this Institution, Mr. Wood, the manager of the South Hetton Coal Company, where the Sussman lamps are in use, has read a paper before the Institute of Mining Engineers, and he gives some figures. I think his figures are not exact, because he gives them in pence per week. He gives the cost of the upkeep of the battery as one penny per week, evidently an estimate, but he brings out the total result to 4·82 pence per week. My calculation showed that for 600 lamps the cost was 7·8 pence per week, and if the same attendants could run a thousand lamps, which they probably could, the cost came down to 6·5 pence per week. I also stated that those figures were on the supposition that the colliery bought the batteries here in London. If they made the batteries, naturally the cost would come down, and Mr. Wood is making his batteries, so I take it that he practically confirms my figures. Mr. Mitcheson, as he stated, has only just begun to use the Sussman lamp; possibly when he comes to renewals he will alter his figures. Mr. Hall, Inspector of Mines, wrote challenging, as I understood it, electrical engineers to produce a lamp which would be carried on the cap. My view of that is that the suggestion is a remark-

Mr. Wilkinson.

a rapid acceleration of the tubs from rest, and the usual interlocked switch lever for reversing and varying speed by resistance in the rotor circuit answers exceedingly well for this kind of work.

Mr. Sayers.

Mr. W. B. SAYERS (*communicated*): I was greatly interested in Mr. Ravenshaw's paper and in the discussion which followed it. With regard to the paragraphs on "Switch Gear for Motors" and "Motor Starting Switches," Mr. Kapp anticipated me by inquiring why Mr. Ravenshaw does not use the method of connecting up a starting resistance in which the armature, shunt coils, and starting resistance are coupled up in series forming a closed circuit, and which obviates any difficulty from inductive effects of the shunt, both as regards sparking and danger to insulation. I am constantly meeting with cases where other arrangements have been adopted and have given trouble, and invariably change them to the one described with perfectly satisfactory results.

One very important point in favour of it is that a broken connection immediately asserts itself, whereas a break in a non-inductive resistance connected in parallel with the shunt may remain undiscovered or may be neglected until damage has been done. Liquid resistances, as made, give trouble in my experience owing to steam, and salt or soda crystals, destroying the insulation; but assuming that a satisfactory design could be made, it is a serious disadvantage that in the case of shunt motors the closed circuit method of connecting with starting resistance cannot be used.

As regards the use of a non-inductive resistance in parallel with series coils, I would point out that if anything like the same proportions were adopted as Mr. Ravenshaw recommends for shunt coils, namely, that the resistance should be equal to twice that of the coils, there would be serious interference with the characteristic of the motor unless the coils were designed to be shunted with such a resistance.

The waste of energy which would result with a resistance coupled permanently in parallel with the series coils is, I think, not warranted; either the resistance should be coupled in by the switch just before breaking circuit, or the switch contacts and length of break, and the insulation of the coils should be designed to stand the extra sparking and stresses. The extra stresses on insulation are, of course, small in the case of a series coil when compared with those caused by the breaking of a shunt circuit. I agree with Mr. Ravenshaw that it is better to have starting resistances large enough to be used for regulating purposes without danger. The difficulties with liquid resistances are, of course, greatly increased when they are used in this way, owing to the steam generated.

With regard to the use of compound motors I do not follow Mr. Ravenshaw's argument; if the shunt winding of a motor has been properly designed, the motor will run a little slow when started up cold, and will gradually creep up to its normal speed as the shunt heats up. If the shunt gets too hot there may be worse results than the mere increase of speed of the motor. The objections to compounding where it can be avoided are increase of cost and the necessity of using finer wire on the shunt than would otherwise be

required. The change of speed with heating will take place even in a compound motor, though to a slightly less extent than in a simple shunt motor; and it may be avoided where objectionable by having a rheostat in the shunt circuit which is cut out as the temperature of shunt rises. Mr. Sayers.

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The slow introduction of polyphase machinery into British mines requires explanation. That it is not due to inherent defects or unsuitableness in the special plant I am fully convinced, and I repeat here what I stated eight years ago, that[1] "the future of electric work in mines lies with the polyphase systems."

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Mr. Sydney F. Walker's paper on miners' electric safety lamps raises an important issue with which I have had no recent experience. Personally I tried in the early nineties most of the hand-lamps then exploited, but found all to be either heavy, weak in mechanical details, or difficult to charge quickly and completely, and all too costly in upkeep. The author does not appear to offer any definite solution of the problem, although he indicates the lines on which he thinks a suitable lamp might be evolved with a primary battery. My own experience with primary batteries has not been a happy one, and I do

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Only experiment would have shown that bare bell-wires would not ignite explosive gases when the ringing is effected by simply pinching two wires together at any point. The reason is probably that the spark is extinct before the wires are distant by an amount equal to the mesh of a safety lamp. I believe Professor Thompson found that the slight sparks on the commutator of a good motor did not ignite the gas. It would be interesting to know if he tried this experiment with carbon brushes, because with these the skin resistance is less, and although the spark may be very minute, it is probably longer and more full of incandescent solids than the spark between two pieces of copper.

It would have been interesting if detailed experiments of electrically driven winding engines had formed part of the paper, because these are comparatively unknown, and the reasonable certainty of their satisfactory operation is most important for central power distributions to collieries.

Mr. Ravenshaw's testimony in favour of bitumen cables is noteworthy. Presumably they are cheaper than rubber and lighter than lead-covered. But this by no means settles the matter, witness Mr. Holliday's most interesting communication on the use of lightly insulated, unarmoured slung cables. I cannot but think that if insulated cables are to be used, concentrics are better, cheaper, and equally reliable; leakage usually occurs from the outer and gives warning of a fault which might stop the work. In wet places they do not suffer from porosity of the negative, and they take up less room in the downcast shaft. I have laid and jointed lead-covered concentrics with complete satisfaction, so that the above is not a purely speculative statement. In every shaft temperature variations cause considerable difficulties with cables, and it is not always possible to use the downcast shaft. With fibre cables the dielectric flows downwards, and the fibre of the cable gets dry at the top. Each increase of temperature causes an expansion of the impregnating fluid to occur downwards. In practice almost complete dryness of portions of the cable seems to do no harm whatever for pressures up to 500 volts, except when the dry portion has to be cut for jointing or repairs. It is then exceptionally hydroscopic, and water may get in at the upper end and flow right down the cable, ruining the whole of it.

If after five or six years Mr. Ravenshaw finds that there is no viscous or other flow of bitumen, it certainly has an advantage in this matter; but the use of single cables individually armoured must increase the self-induction of the circuit, and therefore aggravate the viciousness of sparking. The use of steel tubes such as simplex, unless it be made

Mr. O'Gorman. electrically continuous, is, I think, not advisable, in spite of Mr. Ravenshaw's favourable verdict. The supports of the simplex under ground are liable to move, and if the tubing has at any terminal become connected to either pole, the likelihood of a spark between two lengths of tube is considerable, and this spark may occur although the insulation of both poles to earth is perfectly good, because the enamel on the tubing at the point of support frequently gives it an apparently satisfactory insulation.

The President. The PRESIDENT: I will ask Mr. Ravenshaw and Mr. Walker to give their replies at the next meeting.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Associate Members:

Arthur George Cooke, M.A.
Herrmann Oskar Eurich.
William Thomas Leeming.

Associates:

John Daniel Dyson.
Richard John Montague Holmes.
Albert Henry Hunt.
William Richard Kelsey.
Albert Edward Loos.
Arthur Norris Robinson.
Samuel Robinson.
Oscar Fridolf Alexander Sandberg.

Students:

Richard Charles Caldbeck.
John Ridge Hewett.
Robert Valentine Kemp.
Charles William Dilks Peel.
George Wigram Stewart.
Hans Müller Stich.
James Percy Winn.

The Three Hundred and Sixty-third Ordinary General Meeting was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 18th, 1901, Professor JOHN PERRY, F.R.S., President, in the chair.

The minutes of the Ordinary General Meeting held on Thursday, March 28th, were read and confirmed.

The names of new candidates for election were announced, and it was ordered that they should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Members—

John Powell Edwards. | Alexander S. Garfield.

From the class of Associates to that of Associate Members—

William D. Duddell.

From the class of Students to that of Associates—

Arthur B. H. Cope. | Alfred S. Esslemont.
John F. Henderson.

Messrs. J. S. Fairfax and E. A. Howell were appointed scrutineers of the ballot for the election of new members.

Donations to the Library and to the Building Fund were announced as having been received since the last meeting :—To the *Library*, from D. Van Nostrand Company, Mr. C. H. Wordingham, Member ; to the *Building Fund*, from Messrs. W. R. Rawlings, E. M. Malek, Herbert Nash, A. G. Seaman, Hans Stich, J. Grant, W. R. Wynne, H. J. Gridley, and F. O. Hunt, to whom the thanks of the meeting were duly accorded.

The PRESIDENT announced that the Council of the Society of Arts had arranged for a course of "Howard" Lectures, on Polyphase Electric Working, by Mr. A. C.

Eborall, and had kindly placed a certain number of tickets for the course at the disposal of the Institution. He further stated that these tickets would be issued to members in the order of application.

REPLIES TO THE DISCUSSION ON THE PAPERS ENTITLED:

"Electrical Miners' Safety Lamps," by S. F. Walker, Member.

"Some Notes on the Electrical Transmission of Power in Coal Mines," by H. W. Ravenshaw.

Mr. Walker. Mr. S. F. WALKER, in reply, said: Mr. President and Gentlemen—I am in the pleasing position of having very little to reply to. My remarks apparently met the approval in the main of those gentlemen who were kind enough to take part in the discussion. I am asked to correct a misapprehension that appears to have taken place with regard to the gas detecting apparatus that was shown at the last meeting. The apparatus is not the Sussman Company's apparatus; it is a patent of Mr. Prested's. It acts on a totally different principle. The Sussman apparatus acts on the well-known principle of the impingement of the light carburetted hydrogen gas upon finely divided platinum or paladium causing heat, which expands a column of mercury, making an electric contact. The Prested apparatus acts upon the equally well-known principle of the diffusion of gases. A certain quantity of the ordinary atmosphere of the mines is enclosed in a porous chamber, and when the light carburetted hydrogen gas rushes in it works a contact, closing an electrical circuit which sets the lamp alight. I hope I have made that clear. Professor Foster made one or two remarks which I will deal with very briefly. I quite agree with him that if coal-cutting machines were universally applied—as they will have to be, I feel confident, if this country is to hold its own with America and the Continent—the man, instead of having to spend his eight hours in a confined position using the whole of his muscular effort, will merely have to attend to a machine, and will then possibly not mind carrying into his working place a pound or two more in the shape of his lamp, and I hope that will come about. Then Professor Foster objected to my statement as to the locking of the safety lamps. Roughly there are three forms of locks in use in the present forms of safety lamps. One is practically no lock at all; it is merely a set screw. Another is the lead rivet which Professor Foster referred to, which is stamped in the lamp-room, and which a man can open if he likes, but he is afraid to do so because he is afraid of the police court afterwards. If a man did open his lamp and an explosion followed, the police court would not be of much service to anybody afterwards. I am assured by an experienced colliery manager also that the rivet can be worked with a penknife so as to be opened without showing it. Then the other one, and the most successful, is the magnetic lock. A small iron plunger fits into a recess made for it, and it is kept there by a spring, and can only be withdrawn by a magnet. That is not perfect, but it is the best of the lot. The point

Mr. Walker

that I wanted to make in my paper, and the point I wish to make now, is that all of these can be opened. A magnetic lock is the most difficult to open, but even it can be opened, and if it is opened, and if any lamp is opened, the consequences may be disastrous. On the other hand, if a miner opens the electric lamp the only thing he does is to put his light out. The difference is the same as between the man who has matches in his pocket and the man who has not. If a man has matches in his pocket he may use them; if he has not matches in his pocket he cannot. Then Professor Foster also mentioned the point of carbonic oxide. He said that carbonic oxide was only found where there was combustion. I thought I had made it clear that you always have carbonic oxide after an explosion. When you have an explosion you also have following the explosion, sometimes as the cause of the explosion, the ignition of a large quantity of coal-dust which is lying about the mine. You do not have perfect combustion with the coal-dust, but the first stage of combustion, the combination of the one atom of oxygen with the one atom of carbon, and you have this deadly carbonic oxide formed. The first thing which happens after an explosion is that an exploring party goes into the mine and endeavours to rescue whoever may be left alive, and it is of the very utmost importance not only that carbonic acid shall be found, which the ordinary lamp will indicate by going out, but also that carbonic oxide shall be indicated, and there is no mining lamp at present which indicates carbonic oxide, so that the exploring party may be in carbonic oxide and not know it, and may be getting a deadly dose of it. It appears to me that a gas detecting apparatus which will also show carbonic oxide, whether it is attached to an electric lamp or whether it is taken independently, will be of immense service after an explosion. I think those remarks also deal with what Mr. Atkinson, the Inspector of Mines, stated. Mr. Mitcheson objected to my statement as to the cost of the upkeep of the Sussman lamp. I am in the position since the last meeting of being able to put corroborative evidence before the present meeting. Since the last meeting of this Institution, Mr. Wood, the manager of the South Hetton Coal Company, where the Sussman lamps are in use, has read a paper before the Institute of Mining Engineers, and he gives some figures. I think his figures are not exact, because he gives them in pence per week. He gives the cost of the upkeep of the battery as one penny per week, evidently an estimate, but he brings out the total result to 4·82 pence per week. My calculation showed that for 600 lamps the cost was 7·8 pence per week, and if the same attendants could run a thousand lamps, which they probably could, the cost came down to 6·5 pence per week. I also stated that those figures were on the supposition that the colliery bought the batteries here in London. If they made the batteries, naturally the cost would come down, and Mr. Wood is making his batteries, so I take it that he practically confirms my figures. Mr. Mitcheson, as he stated, has only just begun to use the Sussman lamp; possibly when he comes to renewals he will alter his figures. Mr. Hall, Inspector of Mines, wrote challenging, as I understood it, electrical engineers to produce a lamp which would be carried on the cap. My view of that is that the suggestion is a remark-

Mr. Walker. ably good one. If mining engineers are prepared to accept a lamp which the miner can carry in his cap or in his buttonhole or in his hand, to be run by a battery which you can strap across the shoulders or round the body, or anywhere you like, half the difficulties disappear; the problem is practically solved, in my opinion. You can do almost what you like nowadays with a battery which you can strap round a man's body. There are batteries now being used for the electrical ignition of the charge in the petrol engines of auto-cars which practically do all that you would want in the matter of the electrical lamp. They are a little bit larger than you want there, but the thing could be done; at any rate that is the view I take of it. If the working collier and the mining engineer are prepared to accept a lamp like that, they can have it to-morrow.

Mr Ravenshaw. Mr. H. W. Ravenshaw: I propose to take the various points that were raised as they were taken in the paper—the engines, the cables, and the motors, and so forth. Mr. Barnes asked a question about the use of winding engines for driving the dynamos. I meant, of course, that they were old winding engines; they were not used for winding but for driving dynamos. Mr. le Neve Foster and Mr. Mitcheson spoke about the question of various things falling down the shaft. I tried to perpetrate a small joke by saying that corves were in the habit of falling down the shafts, and it seems to have hit most of the colliery gentlemen that were here, because they all said that corves do not fall down the shaft. I have known several instances where they have done so. Curiously enough, I was at a colliery yesterday where the manager told me that only a fortnight ago two corves had been pushed into the shaft on a Sunday, one on the top of each cage, by some malicious persons. The cages were smashed, the pit stopped for four or five days. Of course, a corve weighing two or three cwt. falling down 500 or 600 yards does a great deal of damage. I have never known any cables to be actually cut through, although I have known them to be knocked about a good deal. It was asked how the cables were generally protected. In timbered shafts it is very easy. One puts them at the back of the cross timbers where they are not likely to be injured. In a case where there are no timbers, it is advisable to put them down at the side of the cages. A corve cannot fall right out of the cage, but it will sometimes come partly out and hit against the side of the shaft. The cable, of course, should never be put where corves will hit the side. I know of one big colliery where they wind at the rate of 45 miles an hour, and you can see the marks on the side of the shaft where the corves sometimes hit. With regard to putting the cables in the shaft, I take the drum wherever it is possible—you cannot always do it—down to the bottom of the shaft, and then fasten the cable on to the cage, and wind up. It is a very quick matter. I have put cables in on a Saturday afternoon, and the whole thing has been completed and working in a very few hours. Where there is timbering and the cable has to come behind the timbering, you lower a wire rope down at the back of the timbers and bring the cable up in the same way, but of course you cannot use the cage. The plan that I have always adopted—and I think it is the best plan—of fastening the cables up, is

Mr. Ravenshaw

to make some very big cleats. The Callender Cable Company devised this method, and I have never had any trouble with it. You get two thick planks and cut two grooves into them. You then put some bolts through and cramp the two planks together with the cables longitudinally in between them, so that you get a cleat something like 6 feet long or more. These cleats are put at about every 100 yards in the shaft, and hang from hooks with a tensioning arrangement. That is, of course, with an armoured cable. I have always used armoured cable for the last seven or eight years. I think it was Mr. Mitcheson who said that the cables could be jointed in the shaft. I never have done that. The deepest shaft I have worked in is 600 yards, and you can easily get cables of that length. Mr. Holiday's arrangement of cables where he uses a plain conductor with merely a braiding on is very interesting. He suspends the cable by an insulator at the top; he has another insulator at the bottom and leaves the whole 600 yards loose. He tensions the cable just like he would do a rope guide. That is a very good plan, I daresay, but we must remember that Mr. Holiday is an electrical expert and is constantly in touch with that particular colliery. Where the ordinary people of the colliery work the thing, I do not think that his system of cables would be very suitable.

Mr. Mitcheson asked whether I found any corrosion of the cleats where they cramped on to the iron. I have not found any corrosion. Mr. Peak mentioned the question of soldering joints. I have never known of a pit where we were allowed to do any soldering at all. Mr. Kapp and Mr. Sayers took exception to the non-inductive resistance which I said I had used. They said that it was an extremely wasteful thing to do. I had some shunt motors the other day which only took one half of one per cent. in the shunt coils As a rule, you can get them absorbing from that to 1½ per cent. The resistance I generally use is about equal to the shunt. After all, you are only losing a very small percentage. The great point that Mr. Kapp and Mr. Sayers did not seem to see was that if you connect the resistance permanently and fix it so that it cannot come undone, you may break the shunt without getting a tremendous flash. Very big motors are often used, and it makes an enormous flash if you get a 500-volt shunt broken. The switch-gear is often right away from the motors; sometimes 15 or 20 feet in haulage plants, as the man has to be where he can see the trains coming up. The switch is not close to the motor, and if you carry a shunt wire from a big motor, or even a small one, it is very likely to get broken some time or other and disconnected, and then there is trouble. It is extremely disastrous to the motor to break the shunt, both from the question of the breakdown of the insulation and of igniting gas. Extreme economy does not have to be considered in a pit. People are always talking about 1 or 2 per cent., but the great thing is to get the work done. Electricity is so much more economical than most other methods of transmitting power that it really does not matter if you do lose 1 or 2 per cent., but you must not use an arrangement which is going to break down. I was very surprised to find that there was a good deal of discussion on the question of grammes *v.* drums. Several gentlemen said that they would not have a drum armature in the pit.

Mr. Ravenshaw.

I said that I would not have a gramme armature in the pit. Like most electrical engineers, we contradicted each other flatly. I should like to point out that tramways do not as a rule use the gramme armatures, and that the modern barrel-wound drum armature is far superior to everything else that has ever been made in the way of continuous-current machines, and particularly superior to a gramme. Mr. Holiday and various other gentlemen seem to have been unfortunate with their drums. I think they must have used the old-fashioned wire-wound drum with the wires crossed over the end. These are quite unsuitable for pit work. I designed some barrel-wound coal-cutting armatures some time ago, and I am told that one has never been known to break down. Mr. Kapp asked a question with reference to my remark that certain armatures were insulated with paper. The conductors were insulated with cotton, but the whole of the cores were insulated with paper. Mr. Barnes said that he used a rope drive and belt drive for underground work, particularly in wet places. I can quite agree with him there. I have a number of motors all over the country under my charge which are driven with belts and ropes, and give entire satisfaction. For a stationary hauling engine you can get very good result with belts, and it is a great advantage not to have the noise of gears down below. Mr. Barnes also raised the question of motors for the surface work, for working the screens and the various work that wasteful steam engines are generally used for. I did not go into that question because I was speaking of the work in the mines, but it is an extremely important one. Dynamo and motor builders have no idea what a field there will be, if they will only push them, for motors on the surface. The amount of coal that is wasted in a colliery is enormous. I know one colliery where they use 70 tons of coal a day, and I am perfectly certain that they could save 40 or 50 tons. Mr. le Neve Foster mentioned the question of electric locomotives on the Continent. I only spoke of plants that I have known, and I have never seen electric locomotives in a pit. With regard to multiphase work, I have always been in the position that I have either wanted to regulate speed or to use gas engines, and wherever I have had an opportunity of using multiphase work one of those points has cropped up, so that I have never used any in collieries. I think that if the multiphase people will produce motors which will have no slip-rings, and which would give a good starting torque, there is an immense field for them. There is a general feeling that when you come to use the slip-ring you are spoiling a really good thing.

The President.

The PRESIDENT: I will ask you to give your thanks to Mr. Walker and Mr. Ravenshaw for the papers which they have read.

The vote was carried by acclamation.

ON TEST-ROOM METHODS OF ALTERNATE CURRENT MEASUREMENT.

By ALBERT CAMPBELL, B.A., Associate Member.

The object of this paper is to describe a number of methods of measurement, some of which are capable of fairly general application, while others are only of use in special cases. Many of these methods are novel, I believe, and most of the others are not well known. Owing to the nature of the subject it is not possible to connect the whole into a coherent sequence, but for convenience of reference I have numbered the methods consecutively.

SECTION A. *Transformer Methods of Measuring Current, Voltage, and Power.*—In the test-room there is no special difficulty in measuring either currents or voltages of ordinary magnitudes; with continuous currents the use of moving-coil instruments renders the measurement of very large or very small values easy and accurate. With alternating currents, however, the measurement of the extreme values is not so easy, and it is for this purpose that transformer methods are specially valuable. Fig. 1 shows two typical methods. In the first method (which is fairly well known) C, the whole current to be measured goes through the primary coil of a transformer the secondary of which is connected to an ammeter A. In Method 2 the current passes through a low non-inductive resistance r_1 giving a small voltage drop V_1 which is transformed up so as to give readings on the electrostatic voltmeter E. As to Method 1, some years ago I investigated[1] the conditions by which the ratio of current transformation can be kept sufficiently constant and independent of frequency. I found that it was necessary to have :—

(*a*) *An air-core transformer or one with a well-closed iron circuit;*

(*b*) *Relatively low resistance and high inductance in the secondary circuit.*

[1] *Philosophical Magazine*, p. 271, Sept. 1896.

Method 2.—It is to Method 2, however, that I wish to draw special attention at present. Here the measuring instrument being electrostatic is unaffected by variations in frequency and, if of good type, has a very high degree of accuracy. [If a reflecting electrostatic voltmeter be set up in a fixed position and a scale for it (say, at 2 metres distance) be drawn by calibration with a potentiometer and direct current, an accuracy of at least 2 in 1,000 is attainable over a large part of the range. In most of the measurements in this part of the paper I have used such a voltmeter.] For currents from 5 amperes and upwards the resistance r_1 should be so small that not more than 0·5 or at most 1 volt is lost in it. If the voltmeter reads to about 120 volts this necessitates a high transformation ratio, at least 1 : 100, in the transformer. To keep the voltmeter read-

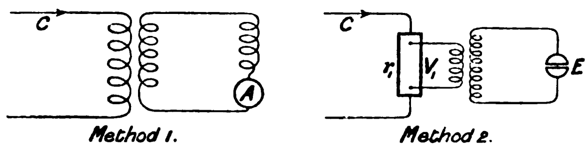

FIG. 1.

ings proportional to the current I find it best to use a transformer with

(*a*) *A well-closed iron circuit;*
(*b*) *A highly inductive primary coil of very low resistance* (i.e., *large time-constant*).

It is difficult to thoroughly carry out condition (*b*) without employing a considerable weight of either iron or copper, but very fair accuracy may be attained with a quite small transformer, as the following instance will show. The core consisted of annular iron stampings of total weight about 1·5 kilos; the primary coil had 100 turns of No. 16 wire, the secondary 10,000 turns of No. 40; r_1 had a resistance of 1 ohm and the resistance of the primary coil was 0·107 ohm. The divergences of the observed ratio V_2 : C from the value 10 are shown in Table I.

TABLE I.

Frequency. ∿ per sec.	Error in Ratio.
	Per cent.
39	— 1·9
86	— 0·8

The primary current at 1 volt (86 ∿ per sec.) was 0·17 ampere. By inserting known resistances in the primary circuit the curve in Fig. 2 was obtained, and thus it was proved that these divergences are (practically) entirely due to the ohmic drop of volts in the primary. If such a

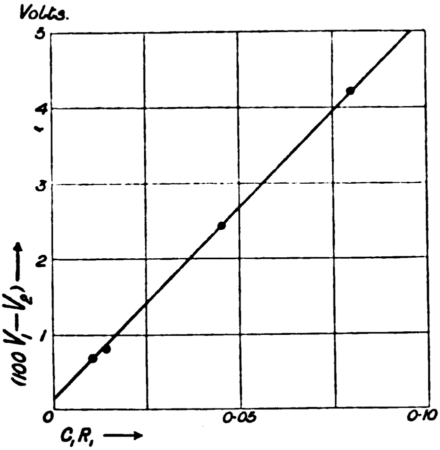

FIG. 2.

transformer is to be used on a circuit of nearly constant frequency the ratio of the windings can be altered slightly so as to give an error almost negligible, or a few extra ends may be brought out to suit various frequencies. Perhaps an easier plan is to have a small range of adjustment on one of the parallel wires forming the low resistance r_1.

It is possible, however, to compensate for changes of frequency by Method 2*a*, shown in Fig. 3. Here the

total current C, after passing through the small resistance r_1, passes through a turn or two on a very small compensating transformer t, whose secondary is connected (reversed) in series with the secondary of T and the voltmeter. As the frequency is raised the transformer t subtracts more and more from the voltmeter reading and thus compensation can be secured.

The advantages of Method 2 are that with one voltmeter and a set of low resistances a very wide range of currents can be measured; also no disturbing inductance is introduced into the main circuit.

It will be noticed that a transformer of high ratio like that described above gives a means of measuring small voltages with very small expenditure of current, but it is

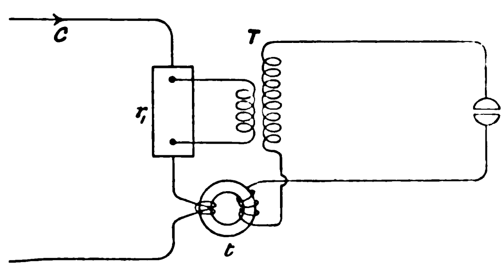

FIG. 3.

mainly to its use in conjunction with a low resistance that I would draw attention.

Measurement of Power.—For the measurement of power (or energy) transformers are often of great assistance, and in several well-known types of watt-hour meter they are employed with success. Under this head I shall content myself with mentioning two methods (3 and 4) shown in Fig. 4, the first due to Mr. M. B. Field, and the second published recently by myself. In both of these a small resistance r is placed in series with the load, and S is a reversing switch. In Method 3 the voltage on the load is transformed down and added and substracted from that on r, giving resultants P and Q, measured on a hot-wire voltmeter. In Method 4 the voltage drop on r is transformed up and the resultants P and Q (similarly obtained) are

measured on an electrostatic voltmeter. For both methods

$$\text{Watts} = \frac{P^2 - Q^2}{4\,mr}$$

where m is the ratio of the transformer.

Method 3 can be used with fair accuracy to measure power with power factors down to 0·1 or even lower. For this the resistance of the primary of the transformer must be made very small, so that the secondary voltage may be almost exactly in opposite power phase to the primary potential difference. (The small angular deficiency may be measured by Method 6 below.) For example, with 50 volts on the load and 50 volts from the transformer, a power factor of 0·1 would give $P - Q \doteq 7$ volts, *i.e.*, the error of

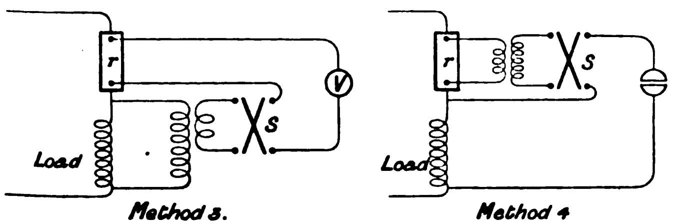

FIG. 4.

reading could be below 2 per cent. even on a voltmeter reading to 100 volts.

Method 5.—The 3-voltmeter method as usually employed has several disadvantages; these are mainly due to the fact that, in order to get good readings, the auxiliary resistance must use up a considerable fraction of the total available voltage, and, what may be worse, tends to alter the wave-forms in the circuit. In the 2-voltmeter methods (3 and 4) this is avoided; there is, however, a simpler modification of the 3-voltmeter method which also gets over the difficulty. This is shown in Fig. 5,[1] where r is a relatively small resistance, and R a very high resistance in parallel with the load W. A convenient fraction $\left(\frac{1}{n}\text{th}\right)$ is picked off R by B, D and the three voltmeter method is applied to A, B, and

[1] Mr. Addenbrooke uses a similar method in his electrostatic wattmeter.

D. The result multiplied by n gives the power taken by W. In another modification the resistance R is put across both r and W, but a more complicated formula is then required.

Method 6.—Measurement of Power Phase Differences close to 180°.

Let the effective voltages be V and X. (1) Let V be nearly equal to X, and let the small difference V − X be measured by an electrostatic voltmeter and a quick change-over key. Then Q the small effective resultant of V and X is found either by a low-reading voltmeter or by the help of a phase turner, or a transformer of high ratio, and an ordinary

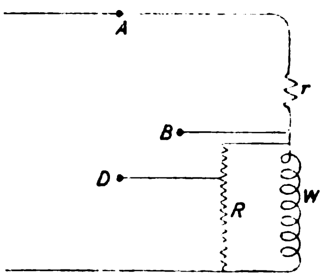

FIG. 5.

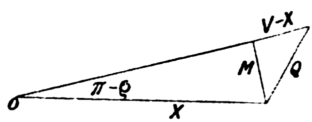

FIG. 6.

range electrostatic voltmeter. Then, as will be seen from Fig. 6,

$$\text{Sin } \phi = \frac{M}{X} \div \frac{\sqrt{Q^2-(V-X)^2}}{X}$$

(2) If V is not nearly equal to X let a high resistance be put across the greater (say V) and V′ a fraction of it picked off as nearly as possible equal to X. V′ and X are then combined as in (1). [The transformer must not be used here for measuring Q.]

I have found the above method useful for measuring approximately the power lag between the primary and secondary (open) potential differences in transformers.

In one case, for example, the lag was found to be (180° − 0·15°). Similarly the lag between two independent voltages very nearly in phase may be measured by reversing one of them and proceeding as above.

SECTION B. *The testing of Watt-hour Meters.*

I. *Real Non-inductive Loads.* When sufficient power is available (at the proper frequency), the tests are usually easy, the chief difficulty sometimes being to find the gearing ratio between the quickest moving part and the dials, for some of the makers cannot be persuaded to mark this clearly on the meter.[1] When the loads are above 2 or 3 kilowatts, special non-inductive resistances are desirable in addition to lamps. I have found that a very convenient and cheap type of resistance frame for this purpose consists of strips of copper-nickel each 1 cm. broad, 1 metre long, and capable of carrying 50 amperes. As the strips sag with the heat developed they are pulled taut by light springs which pull at the middle points of the strips. With such frames a

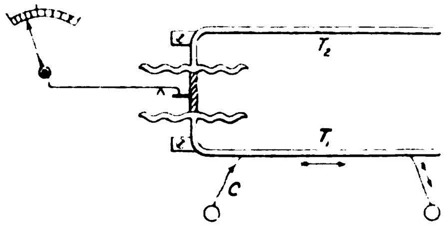

FIG. 7.

steady non-inductive load is easily obtained. Some meters are so much affected by inductance in the load that the introduction even of a small Kelvin balance (to measure the current) is undesirable. The want of a non-inductive ammeter in this and other cases led me, seven or eight years ago, to devise and make a thermal ammeter which, although I exhibit it now only as a curiosity, has some points of interest about it. It consists (Fig. 7) of a form of differential air thermometer in which the bulbs are replaced at each side by thin-walled metal tubes T_1 and T_2 of small diameter (1 to 2 mm.); each of these is connected with a small aneroid chamber of extremely small internal volume. These chambers act against one another, and their differential action is magnified by ordinary aneroid mechanism as shown in the Figure. The current to be measured is passed along the tube T_1 (or a set of tubes electrically in parallel) while the tube T_2 in the same enclosure acts as compensator.

[1] The Board of Trade might reasonably insist on this being done, I think.

The use of the thin hot tube acting as its own air chamber is to give the maximum quickness in attaining steady readings. To compensate for the decrease in the expansibility of the air as the temperature rises, the hot tube was made of a material having a considerable resistance-temperature coefficient. Such a hot-tube ammeter, though non-inductive, dead-beat, and low in resistance, was scarcely accurate enough for careful testing work, but I think the principle is worth recording here.

II. *Inductive Loads.*—As several types of energy-meter suitable for measuring inductive loads are now in common use, it is often necessary to test with inductive loads going down to power factors of 0·6 to 0·7. To use an ordinary wattmeter as standard is objectionable, as its errors may be

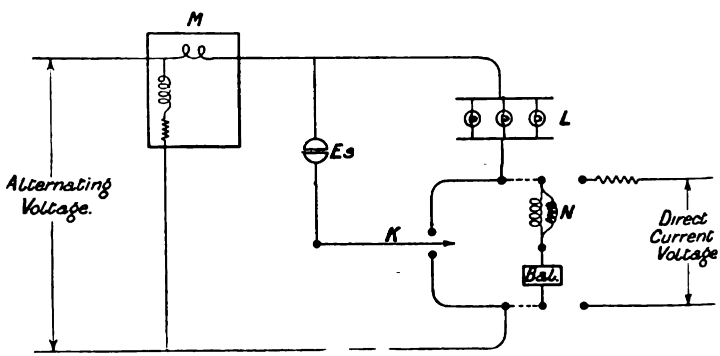

FIG. 8.

as large as those of the watt-hour meter under test. I have used the following method (7) for some years past and have found it convenient and accurate.

Method 7.—This is shown in Fig. 8, in which M is the watt-hour meter under test. The load consists of a non-inductive resistance L in series (through mercury pools) with an inductive part consisting of a Kelvin balance and a set of copper coils (N) wound inductively. In order to be able to make sudden measurements of the resistance of this inductive-portion, mercury cups are so arranged that it can be quickly switched over into connection with a direct-current circuit and the resistance measured by reading current and P.D. on a Weston instrument. While the meter is running, the current C is read on the balance, and by the

help of the switch K the voltage V on L and the total voltage U are read on the electrostatic voltmeter Es.

If r = mean resistance of the inductive part, then—

$$\text{Power} = \text{CV} + \text{C}^2 r,$$

and—

$$\text{Power factor} = \frac{\text{W}}{\text{CU}}$$

In practice r is made as small as possible, so that a small error in $\text{C}^2 r$ has a very small effect upon the value of W, while the CV part can be measured with extreme accuracy. The coils which make up N must have no iron near them, eddy currents must be avoided, and mutual induction must be guarded against except where two of the coils are identical in winding, in which case their impedance in parallel can be conveniently varied by varying their relative positions. The method is also suitable for testing wattmeters.

Method 8.—I have sometimes found it convenient to use

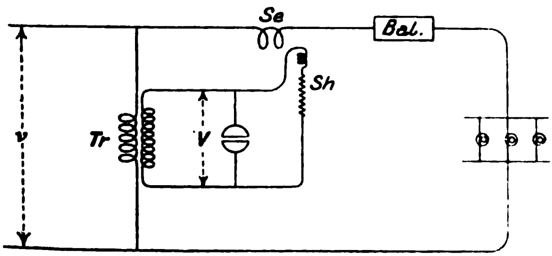

FIG. 9.

a somewhat different method by which the measurement of resistance is rendered unnecessary. This consists simply in measuring w, the power in the highly inductive part, by the 3-voltmeter method (or by an ordinary wattmeter), the total power being CV + w. Since w can be made to be only a small part of the whole power, this is accurate enough and the coils N may here have iron cores.

III. *Fictitious Loads.*—Unfortunately it very often happens that sufficient power (at the proper frequency) is not available to allow the meter to be tested with the actual loads at which it is to be used. It thus becomes necessary to arrange fictitious loads whose action on the watt-hour meter shall be practically identical with that of the corresponding real loads.

Method 9.—When the source of supply can furnish the

current, but not at a voltage quite high enough for the load required, the well-known arrangement shown in Fig. 9 may be used. The shunt coil *Sh* is disconnected from the series coil *Se*, and is connected with a transformer *Tr* which raises the supply voltage v to a suitable value V. The voltage v must be high enough to allow the series circuit (series coil, balance, and lamps) to be practically non-inductive.

Method 10.—When a large current is required, a method which I have published recently will be found useful. In it the large current obtained at a low voltage passes through the Kelvin balance, the series coil of the meter, and a low non-inductive resistance; a transformer of high ratio, with its primary across this low resistance, furnishes from its secondary the volts for the shunt circuit.

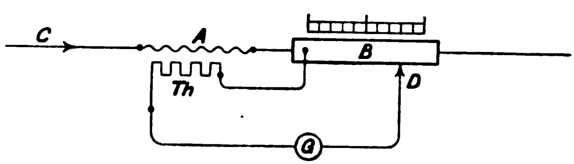

FIG. 10.

SECTION C. *Thermopile Methods.*—A well-known, but little used, way of measuring a current consists in passing the current through a conductor near which are one set of junctions of a thermopile. With rightly chosen conditions, the deflections of the galvanometer connected with the pile are practically proportional to the square of the effective value of the current. In common with many other thermal methods, the action is dead-beat, but there is usually the accompanying disadvantage of sluggishness, the zero point not being regained instantly on switching off the current. By making the hot wire and the junctions extremely small, this sluggishness can be much reduced. I have tried a thermopile of iron and nickel wires of 0·15 mm. (6 mils) diameter; from a deflection of 100 divisions (400 mm.) the light-spot, after the switching off of the current, returned to within 1·5 divisions above zero in 30 seconds, and was still 0·5 division from zero after 75 seconds. This is prompt enough for many purposes; and it is no difficult matter to braze the

junctions of such a thermopile. I have succeeded in brazing junctions of much thinner wire and gained considerably in promptness of working, but this gain scarcely repaid the extreme difficulty of construction.

Method 10.—I may mention here a somewhat interesting null method of measuring continuous current which I have tried; it is shown in Fig. 10. The current passes (wholly or in part) through the thin wire A and also through B, a strip or rod of very low resistance. The heating of A by

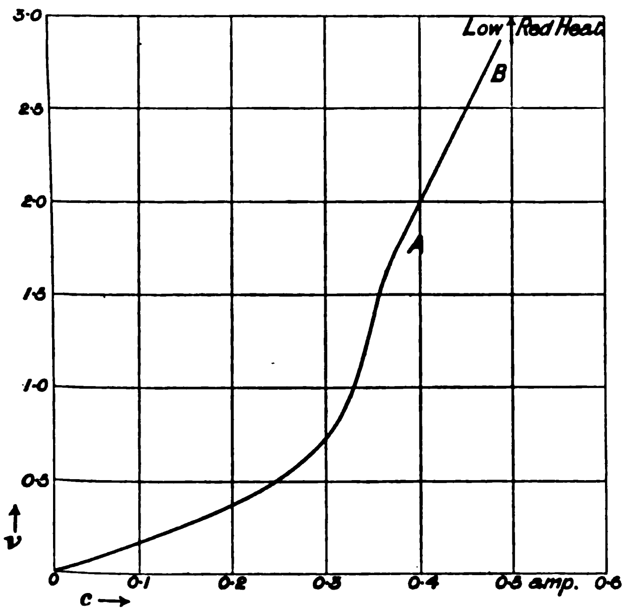

FIG. 11.—Nickel-Wire Diam. 0·05 mm. (2 mils).

the current causes the pile *Th* to give an E.M.F. e which is balanced against a part of the voltage-drop along B by moving the slider D until the deflection of the detector galvanometer G is brought to zero. Here $e = k\,C^2$ and $v = r\,C$, r being the resistance of the fraction of B for which $e = v$.

Then $r = k\,C$, and hence the graduations of the scale of the slider are directly proportional to the current measured.

SECTION D. *On obtaining Steady Currents.*—In accurate testing work it is of great advantage to be able to obtain very steady currents and voltages. By the help of an auto-

matic thermal arrangement I have succeeded in obtaining very exact regulation, even when the supply voltage is varied by 10 or 12 per cent. The method depends upon the alteration of resistance due to rise of temperature. In the following description I shall take a concrete instance with wires of nickel and manganin as typical of conductors of large and small temperature coefficients respectively.

If a curve be drawn for any conductor showing the connection between c, the current through the conductor, and v, the voltage applied to its ends, the form of the curve will depend on the material of the conductor and on the temperatures to which it is raised by the current. It is

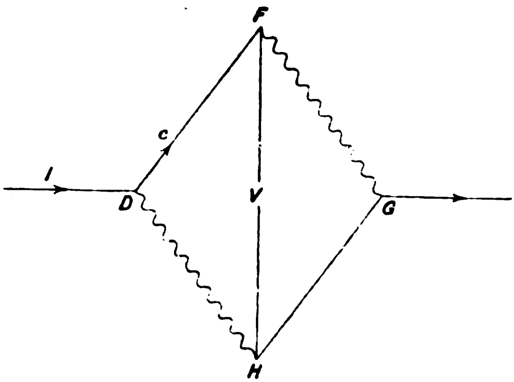

FIG. 12.

convenient to call this curve the *Characteristic* (*Curve*) of the conductor. I assume that, in drawing the characteristic curve, steady conditions of temperature are reached at all points. For manganin, not overheated, the characteristic is practically a straight line whose steepness measures the resistance of the conductor, but for a thin wire of nickel the characteristic curve is of the form shown in Fig. 11, which is drawn from an actual experiment with wire of 0·05 mm. (2 mils) diameter. It will be noticed that *the higher part of the curve* (*from A to B*) *is very nearly a straight line.*

Method 11.—Now let a Wheatstone's bridge be arranged, as in Fig. 12, in which the arms DF and GH are equal resistances of nickel, while DH and FG (also equal to one

another) are of manganin. In Fig. 13 let OAB and OK be the characteristic curves of DF and FG. Then it is easy to show that, as long as the branch from F to H is kept on open circuit, the potential difference from F to H, for any particular value of the current c, will be proportional to the

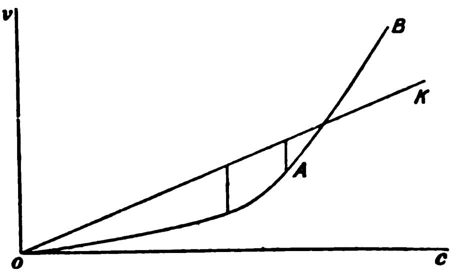

FIG. 13.

vertical distance between the two characteristic curves. It is easy to choose the relative values of the nickel and manganin resistances, so that OK shall be parallel to the straight portion AB, as in Fig. 14, and when this is the case nm will be constant from A to B, and thus *V will be practically constant for all values of the current c corresponding to the part AB.*

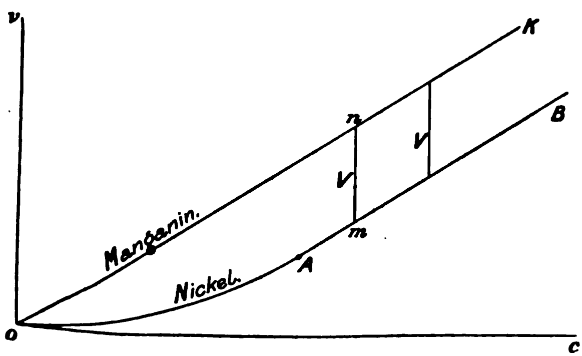

FIG. 14.

As I show in Appendix II., this regulation also holds even when current is taken across FH, the constant value of V, however, depending on the current taken. The construction for this case is shown in Fig. 15. OL is taken equal to C, the current through FH, and LK is drawn parallel to

the characteristic for the manganin wires; V[1] will then give the value of the constant voltage from F to H. Thus it is possible to obtain very constant voltage and current, although the main current I (Fig. 12) be drawn from a variable source such as the mains of a supply company. With actual apparatus the maximum steady voltage which I have obtained has been about one-third of the supply voltage used; with alternating currents the use of a transformer makes this limitation of small moment.

Compensation for Variation of Temperature of Enclosure.—Unless the temperature of the enclosure containing the nickel wires can be kept constant, it is necessary to introduce compensation for temperature. This can be done by replacing part of each manganin resistance arm by copper

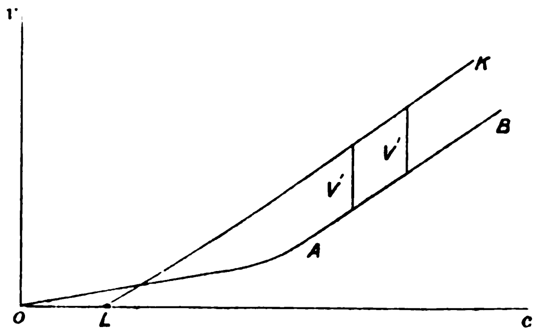

FIG. 15.

(in the same enclosure as the hot arms), sufficient cooling surface being allowed so as to prevent undue heating by the current. The curves in Fig. 16 show the results of experiments at enclosure-temperatures of 24° and 37° C. with a regulator compensated in this way. The arms of the regulator (in cyclic order) consisted of a 2-mil nickel wire of 3·5 ohms; 20 ohms of manganin in series with 3·4 ohms of copper; and two equal manganin resistances of 125 ohms each. It will be noticed that near 0·45 ampere both the regulation and the temperature compensation are satisfactory. The level part of the curve (Fig. 16) corresponds to temperatures of the nickel wire between about 400° and 600° C.

It would, I believe, be possible to obtain more extensive and better regulation by using platinum or other material

instead of nickel, since the nickel has an abrupt bend in its temperature-resistance curve. Also, by replacing parts of the manganin arms by heated nickel, say, of larger diameter

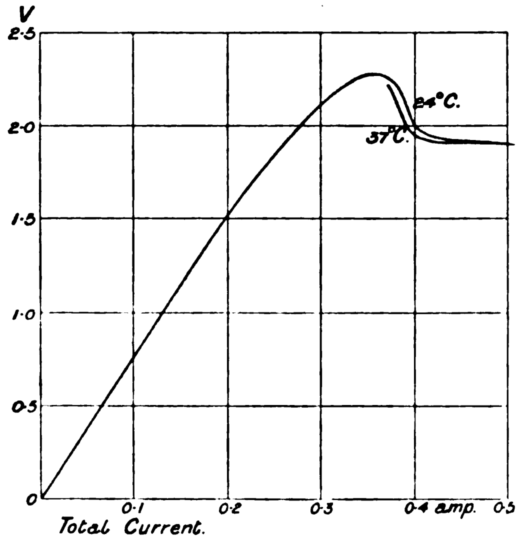

FIG. 16.

than that used in the other arms, it would be possible to make the upper characteristic bend up slightly, as in Fig. 17, and so to attain more exact parallelism of the two curves, and hence better regulation. Again, by applying a once-

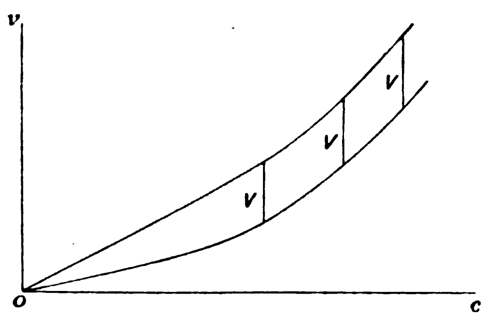

FIG. 17.

regulated voltage to a second regulator a much greater steadiness would be obtained.

Method 12.—It will be noticed that, in the above regulator, the function of the Wheatstone's bridge is merely to

obtain the difference between the voltages on the nickel and the manganin resistances. With alternating currents the same may also be done by means of a transformer, as shown in Fig. 18, where the transformer Tr is connected so as to give a regulated voltage at V.

Uses of Regulated Voltages.—It is not difficult to find instances where regulated voltages would be of use in testing work; standard glow-lamps may thus be run at constant brightness, shunts of watt-hour meters may be kept on constant voltage during test; with constant voltage the mere measurement of the current taken by an inductive coil usually gives an approximate indication of the frequency; a constant current from a supply circuit may be used to get direct readings in a simple electric resistance thermometer.

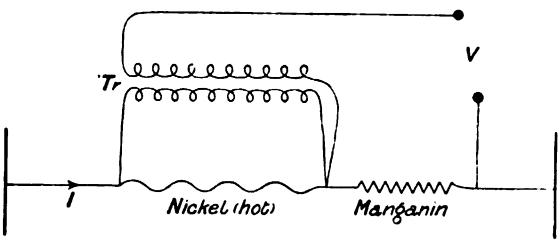

FIG. 18.

SECTION E. *Null Methods of measuring Current.*—If in the Wheatstone's bridge arrangement the resistances are so chosen that the characteristics intersect, as in Fig. 13, then we may obtain, for I and V, a curve such as that in Fig. 19, which is drawn from actual experiment (with direct current). With proper temperature compensation V vanishes for a perfectly definite value of the total current I, and if a sensitive detector be added the arrangement becomes *a thermal standard of current.* I have found a telephone with an intermittent contact in its circuit a convenient means of detecting the vanishing of V, the intermittent contact being of advantage even with alternating currents. The accuracy of such a standard is considerable.

Method 13.—If such a combination be put in series with a resistance having a part adjustable by a sliding contact, as in Fig. 20, it furnishes a simple null method of measuring a

voltage (*e.g.*, of a supply company) which varies between small limits ; the slider is adjusted to give silence in the telephone, and the corresponding value of the voltage is shown by the position of the slider. With alternating current the transformer method (12) is also applicable here, but a de-

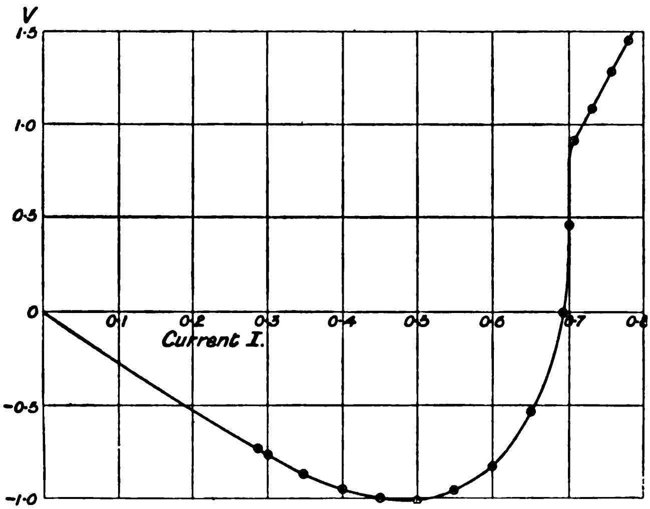

FIG. 19.

tector other than a telephone is necessary, for since the transformer alters the wave-form slightly it is found impossible to get any position of complete silence with the telephone.

Method 14.—In conclusion, I may point out that if a voltmeter be put across V (Fig. 12) it will be seen from the

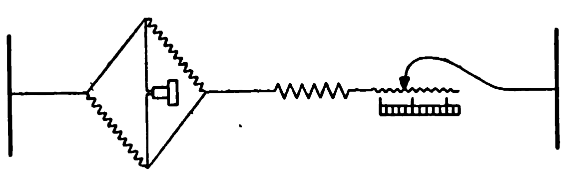

FIG. 20.

curve in Fig. 19 that a very open scale can be obtained corresponding either to the total current I or the outside volts ; this furnishes a thermally "set up" instrument. I have found platinum better than nickel for this. Compensation for temperature can be applied as in the other methods.

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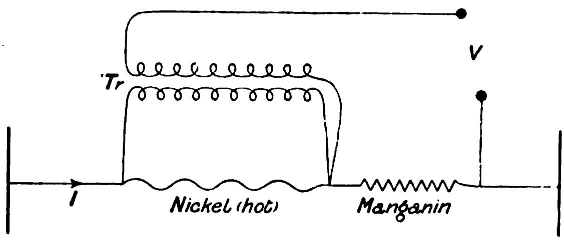

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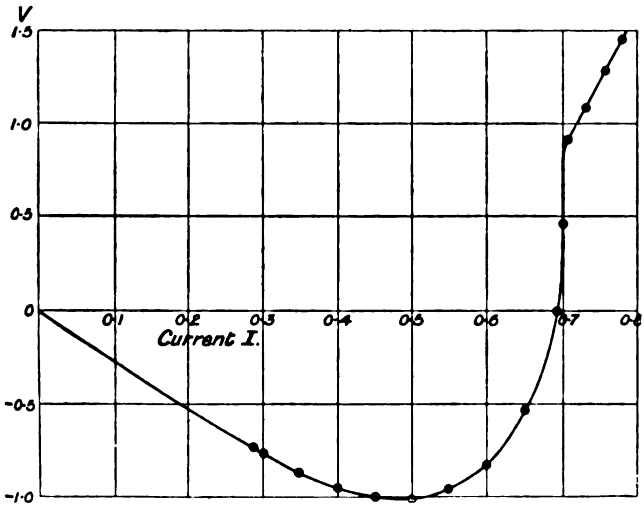

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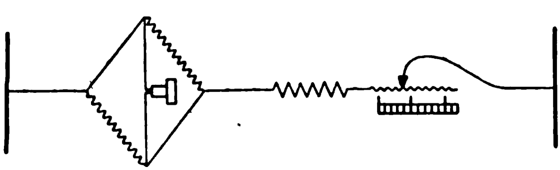

FIG. 20.

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APPENDIX I.

In connection with my remarks on the measurement of power, I should like to draw attention to an instrument invented by Professor Riccardo Arnò for measuring the phase difference between two currents. It consists of two co-axial coils carrying the given currents A and B, and a search-coil S connected to an electro-dynamometer. (For simplicity suppose $A = B$). The main coils are by trial placed at such an inclination to one another that the search coil shows the same effective induced voltage in all positions as it is turned co-axially to the other two. Professor Arnò shows that with sine-curve wave-forms the angle between the main coils is then the supplement of the angle of phase difference between A and B. I proceed to show that, for any wave-forms (not containing direct current components) the phase angle obtained is the power phase difference between the currents A and B. In Fig. 21 let the position angles of the three coils be as shown, OX,

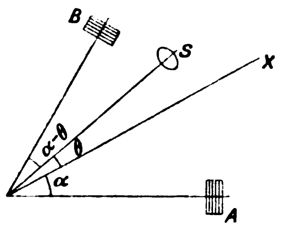

FIG. 21.

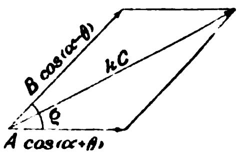

FIG. 22.

the initial line bisecting the angle AOB.

Let ϕ = angle of idleness between A and B.
$2a$ = angle of position between main coils.
Also let C = current in search coil.

Then, by Fig. 22, kC is the resultant of $A \cos (a + \theta)$ and $B \cos (a - \theta)$ at an angle ϕ.

Hence—

$$\begin{aligned} k^2C^2 &= A^2 \cos^2 (a + \theta) + B^2 \cos^2 (a - \theta) \\ &\quad + 2AB \cos (a + \theta) \cos (a - \theta) \cos \phi ; \\ \therefore\ 2k^2C^2 &= A^2 + B^2 + 2AB \cos \phi \cos 2a \\ &\quad + [(A^2 + B^2) \cos 2a + 2AB \cos \phi] \cos 2\theta \\ &\quad - (A^2 - B^2) \sin 2a \sin 2\theta. \end{aligned}$$

If C = constant for all values of θ,

then— $$(A^2 - B^2) \sin 2a = 0,$$

and— $$\cos \phi = -\frac{A^2 + B^2}{2AB} \cos 2a.$$

Since— $$A = B \therefore \cos \phi = - \cos 2a.$$

Q. E. D.

Note.—In the above I have assumed that there is no disturbing mutual induction between the search coil and the main coils.

APPENDIX II.

Mathematical Investigation of Bridge Regulator.—As in Fig. 24, let the equation to the upper straight part of the nickel characteristic be—

$$c = \frac{v}{m} + c_0,$$

where c of course must be kept within its proper limits. If r = resistance of each nickel wire, then—

$$\frac{1}{r} = \frac{c}{v} = \frac{1}{m} + \frac{c_0}{v} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

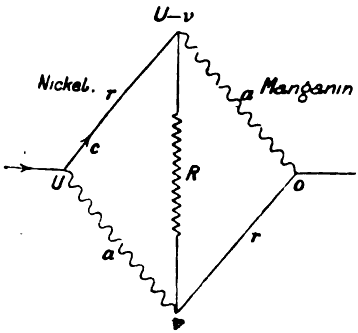

FIG. 23.

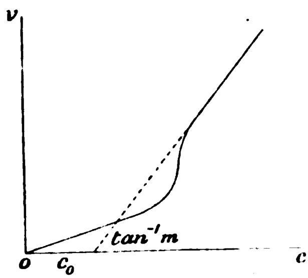

FIG. 24.

Now let the bridge potentials and resistances be as in Fig. 23. Let

$$\begin{aligned} V &= \text{voltage on R} \\ &= U - 2v. \end{aligned}$$

If the outer voltage U be variable, let us find the condition for V = constant.

We have—

$$v = \frac{U - V}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

and—

$$\frac{v}{r} - \frac{V}{R} + \frac{v - U}{a} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Hence, from (1) and (2)—

$$\frac{U - V}{2m} + c_0 - \frac{V}{R} - \frac{U + V}{2a} = 0,$$

or—

$$U\left(\frac{1}{m} - \frac{1}{a}\right) + 2c_0 = V\left(\frac{1}{m} + \frac{2}{R} + \frac{1}{a}\right)$$

Since V is to be constant,

$$\frac{1}{m} = \frac{1}{a} \quad \therefore\ m = a \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Hence—

$$V = \frac{2c_0}{\frac{1}{m} + \frac{2}{R} + \frac{1}{a}} = \frac{c_0}{\frac{1}{a} + \frac{1}{R}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

also

$$v = \frac{c_0}{\frac{1}{r} - \frac{1}{a}}$$

Thus we see that, whatever the value of R, the condition for regulation is simply that $m = a$, *i.e.*, that the characteristics of the nickel and the manganin should be parallel (for the upper straight part of the former). Equation (5) gives the value of the regulated voltage for any particular value of R.

NOTE ON THE USE OF THE DIFFERENTIAL GALVANOMETER.

By C. W. S. CRAWLEY, Member.

I do not wish to suggest that I am bringing forward anything new, but rather to say a few words in favour of an old but very effective instrument, which has fallen into disuse, and to show a practical way of using it for modern work.

In early days the differential galvanometer was used a great deal; when the bridge came into general use it was shelved, as the scope of the bridge was so much greater, and it sufficed for all the resistance measurements then required. Another reason why the differential galvanometer went out was, I think, this: People were used to the old pattern of differential galvanometer with pivoted needle, which was adjusted once for all and remained right. Then the reflecting galvanometer became universal, and the reflecting differential galvanometer when adjusted does not remain right for good, but must be very carefully levelled, and even then is seldom in perfect adjustment. Some year or two ago I wanted some low resistances adjusted which it was impossible to bridge, and so I looked into the potentiometer, which was better, but very troublesome, and this brought me to the differential galvanometer. For I always look on the differential galvanometer as a potentiometer; only, instead of balancing opposing E.M.F.s, one balances the M.M.F.s caused by them.

Now, I knew by sad experience that to adjust a differen-

tial galvanometer was a very great nuisance, so I took the bull by the horns and did not adjust at all, but simply had the galvanometer coils wound double, *i.e.*, with twin wire, and set the instrument up as it was, without adjustment.

In Fig. 1, *a* and *b*, 100 ohms each, are the circuits of the differential galvanometer in parallel, opposed, joined to the battery. In the circuit of *a* is a 0·1 ohm resistance, which can be cut out by a key, and also a slide-wire resistance, *S*, of about 1·5 ohms. In circuit with *b* is enough resistance to about balance. This can be a resistance box. When joined as shown, if *a* or *b* predominates and gives a deflec-

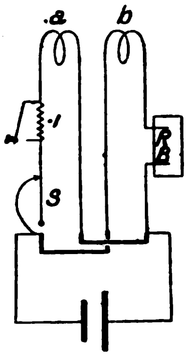

FIG. 1.

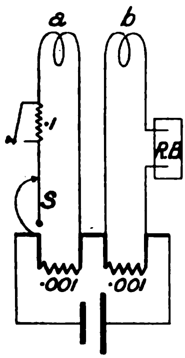

FIG. 2.

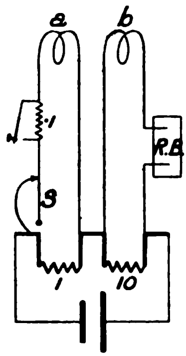

FIG. 3.

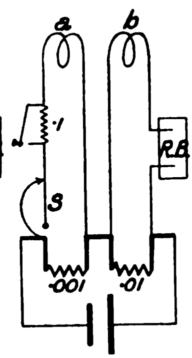

FIG. 4.

tion, sufficient resistance is added or subtracted by the slide wire till the spot roughly comes to zero. Now depress the 0·1 key; this disturbs the balance by 0·1 per cent. and causes a deflection of some hundreds of scale divisions. If we do not want to read closer than ·01 we need not adjust the balance closer than, say, 10 scale divisions.

We now know that two equal and opposite E.M.F.s at the terminals of the two-coil circuits will balance, so that we can compare any two equal coils with great ease and great accuracy. For example, two ·001 ohm coils, as in Fig. 2. If they are not alike there is a deflection. Pressing the 0·1 ohm key gives the deflection for 0·1 per cent. difference between them, which, with only 10 amperes through them, is about 400 scale divisions, so when working to ·01 per cent. anything under, say, 10 scale divisions can be ignored (which is a great comfort when adjusting).

But we can go a great deal farther; we can join up on to the terminals of a 1 and a 10 ohm standard coil as in Fig. 3, and add resistance to *b* circuit till a balance is obtained. For all-round work an ordinary resistance box will do, but if there is much 10 to 1 work to be done it is sometimes worth having a separate coil of 9 *b* ohms. It was in this ratio way that I used it first; I wanted a set of stretched copper wires, accurately adjusted, for copper conductivity work, of 1, $\frac{1}{2}$, $\frac{1}{4}$, &c., down to $\frac{1}{1024}$ ohm. This would have been impracticable by bridge, and very inconvenient by potentiometer.

But setting the differential galvanometer two to one it was quite easy, the first or one ohm coil being the most difficult, as it had to be done against an outside standard. And the checking is so simple; the galvanometer is set, say, 4 or 8 to 1, and every third or fourth wire compared in the same way.

At a pinch one can go a little further still; a coil differing considerably from the standard can be balanced by adding resistance to *b* coil and allowing for it, or setting to an odd ratio; but this is more troublesome.

Now, as to sensitiveness. With 0·1 volt at the terminals of coils short on to the galvanometer and a ten second swing, we have a deflection of 450 scale divisions for a difference of 0·1 per cent., so that we can compare two $\frac{1}{1000}$ ohm resistances with only 10 amperes and have a deflection of 4·5 scale divisions for ·01 per cent.

As to limits of accuracy and sources of error, the galvanometer can be balanced far beyond anything required. Next the question of perfect contacts; they can certainly be counted on not to be more than $\frac{1}{1000}$ ohm if made rationally, or an error of ·001 per cent. As to temperature, the galvanometer coils are copper, but being wound double remain always at the same temperature.

Thermal contacts may occur at times, but are easily detected and eliminated by reversing the battery current. They are infrequent and small in effect.

For long and continuous testing, especially with a ratio, I like to have a rocking mercury switch which will do the check instantly. When working with ratios, temperature may cause an error; but if the galvanometer is placed so that its temperature remains constant, as shown by a ther-

mometer, the error will not exceed ·02 per cent. A check should be made at the end of the test.

In setting, it is of course necessary to allow for errors in the standards, if they would be within the limits required. It is easily done by deflection.

There is only one inherent error to allow for. That is due to the resistance of the coil circuits of the galvanometer not being exactly the same when they are in balance. This, however, is but small. If the coils differ by a per cent. and they are b times the resistance of the coils under test, the error in the result is $\frac{a}{b}$ per cent. a should be under 1, and b is generally at least 100, so that at the worst the error is ·01 per cent., even when comparing 1 ohm coils or setting 1 to 10 ratio with 1 to 10 ohm coils.[1]

[1] Let the two coil circuits be so adjusted by resistance that in parallel they give no deflection.

Then equal E.M.F.s, at their terminals, always give none.

Now join to the terminals of two equal coils, D, in series.

If the galvanometer circuits are of equal resistance there will be no deflection.

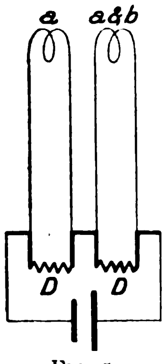

FIG. 5.

But if they are not, but are a and $a + b$ respectively, the E.M.F.s on them will be proportional to the joint resistances and there will be a deflection due to the difference of E.M.F. on the two. The joint resistances are—

$$R_1 = \frac{a\,d}{a + d} \text{ and } R_2 = \frac{(a + b)\,d}{a + b + d}$$

Let $b = \frac{a}{p}$ and $d = \frac{a}{q}$; substitute, and we get $\frac{R_2}{R_1} = 1 + \frac{1}{p + q + pq}$

p and q are large—at least 100; so that error is practically $\frac{1}{pq}$, *i.e.*, if the coils circuits differ by C per cent. the error in the result is $\frac{C}{P}$ per cent., which is of the order of ·01 at most, and can be easily allowed for in setting.

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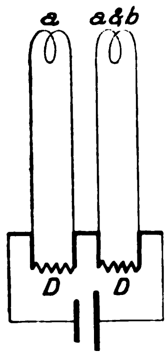

Fig. 5.

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On the table there is a potentiometer which I designed some time ago to get rid of a slide wire, and which is used a good deal now. There are two dials, one of about 16 ohms divided into 150 equal parts, and the other, the whole of which is equal to one coil of the first dial and divided into 100 parts, thus giving the equivalent of a slide wire divided accurately into 15,000 parts, which is ample for practical work, and which cannot be damaged by its natural enemies, wear, pupils or students. It can also be speedily checked, right through, against itself.

Now, just think of the labour of adjusting the 150

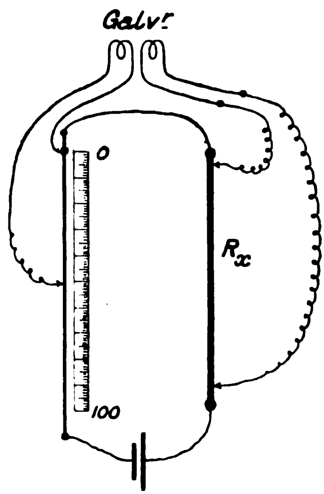

FIG. 6.

contacts of about 0·1 each; and still worse the 100 contacts of about ·001 each by potentiometer or other such means. But by differential galvanometer it is perfectly simple; and the result can be easily checked, as pointed out before, by setting the galvanometer 2 or 3 or 10 to 1 instead of level.

I have also on the table another use of the differential galvanometer method. It is shown diagramatically in figure 6. It is a workshop method of measuring anything between ·1 and ·01, or even less.

In the diagram there is a slide wire of ·1 total in series with the resistance under test and a battery. One coil of a differential galvanometer is applied to the ends of the resistance R by means of stabbers on cords; the other coil

is joined to one end of the slide wire and to the sliding contact, so that it takes the fall over more or less of the wire, the whole length of the wire being divided into 1,000 parts by a scale; each division (about 1mm.) is equal to ·0001 ohm. The wire is about 0·1 inch diameter, so wear does not come in. It works well with 5 A.

In conclusion, I do not suggest the differential galvanometer for ordinary accurate coil work; the Carey Foster method is perfect for that, and I have never sanctioned any accurate coils between 1 and 10,000 being finally tested by any other method. But below 1 ohm it is invaluable, and it makes quite easy a good deal of special work which would not be practical commercially by any other method.

For example, the conductivity of two copper bars can be compared with quite reasonable currents, say 10 amperes for bars one inch square, which gives about four scale divisions for ·1 per cent. with contact points twelve inches apart.

Mr. R. T. GLAZEBROOK: With regard to the methods of measuring alternate currents that were described in the first instance by Mr. Campbell, my own experience is perhaps hardly sufficient to make any remarks from me on that part of his paper of real value. The part that interested me most was the latter part of the paper dealing with the thermal measurement of current by the thermal regulator, which seems to me an instrument that might be of very great use in research, and is certainly marked with very great ingenuity. It depends, I take it, almost entirely, if not entirely, on the properties of these characteristic curves, as Mr. Campbell has called them, which he has shown us on the board. It struck me at once, on seeing that curve, that it would be of considerable interest to know how regularly it was uniformly repeated. The curve for nickel would be a straight line if the nickel remained at a constant temperature while the currents were passing through it, so that of course the form of the curve depends, as Mr. Campbell explains, on the temperature of the nickel. The temperature of the nickel will depend on its surroundings. It will depend also on the nature of the surface of the nickel. I should like to ask Mr. Campbell how far he had evidence of the permanence of the curves, so that when once we had set up the bridge that he has described we might use the instrument for some considerable time and feel secure that its records would be uniform and regular. Then, again, it occurred to me to ask him if he would go a little more fully into the method whereby he standardised the instrument when used as a thermal measurer of current. I have not been able to look into that with care, but it struck me, on hearing what he had to say, that some explanation of the arrangements that were necessary to get the actual value of the current from the readings of the instrument would be of interest. As to

Mr. Glazebrook.

Mr. Glazebrook. Mr. Crawley's paper, that also strikes me as being of very great value and very great interest. I have never used a differential galvanometer myself, although I have made various rough attempts to use one. I was in Berlin about a year ago, and I gathered that at the Reichstalt they were using a differential galvanometer, for resistance measurements, in a somewhat similar method I think, but I do not know how far they were carrying it. I certainly have had no experience of an instrument constructed, as Mr. Crawley has said, without making any attempt to get an accurate magnetic balance between the two coils, but trusting to this adjustment of resistance outside to keep the balance. It seems to me that Mr. Crawley has solved a very difficult problem of adjusting and making standards of small resistances accurately, rapidly, and easily, and that he is to be very much congratulated on the success which has followed this method which he has described to us.

Mr. Trotter. Mr. A. P. TROTTER: I have not had an opportunity of trying any of Mr. Campbell's methods, and I look forward with interest to trying his arrangement for obtaining constant pressure, and the thermal compensation device, which appear to be very promising.

I am glad to say that I have used the method described by Mr. Crawley. Some time ago, one ohm was about the smallest measurement of resistance which was required in the Board of Trade Electrical Standards Laboratory, but of course you are aware that with the increase of potentiometer methods and of ammeters which act by potential difference, it is very common now to have to measure with considerable precision low resistances to carry large currents. Some months ago a ten-thousandth of an ohm to carry a thousand amperes was sent to the Board of Trade for verification. It was a big thing, designed for a laboratory in Canada. We took a good deal of trouble to satisfy ourselves as to its accuracy. It came out wonderfully well, the test having been made by the potentiometer method. When dealing with one or two thousand amperes, the trouble is not so much to measure the current, as to make sure that it is constant while the measurement is in progress. In the potentiometer method which has been introduced recently into the Board of Trade Electrical Standards Laboratory using a low resistance potentiometer, the resistance and the current must be measured by two successive operations. You switch over one way and measure the current, and quickly switch over and measure the resistance, and then switch back again to see that the current has not altered. It generally *does* vary when you are dealing with thousands of amperes, and it is very difficult indeed to keep it steady. To repeat the two measurements several times means a tremendous consumption of current.

I put this to Mr. Crawley, and asked him for his advice, and he suggested the differential method. This differential instrument has been set up; it has not been quite finished in all its details, but we have had it in use for some months, and I find it does all that was promised for it. One of the latest measurements made with it was a pair of resistances of 26 micro-ohms, (0·000,026 ohm), to carry up to 2,000 amperes. Of course, we have some resistances lower than one ohm, but nothing so low as this.

The verification was first made by the potentiometer method using the large "kilo-ampere" balance for the measurement of the current. The same verification was carried out by means of the differential so as to give a comparison betwen the two methods. The resistance used as a sub-standard was a shunt of 0·01 of an ohm capable of carrying from 50 to 60 amperes. In this experiment we did not set the differential galvanometer to a definite ratio, but connected up in series with it a resistance box capable of giving a very high range of ratios. With a current of from 10 to 20 amperes in the circuit, the variable resistance was adjusted until zero deflection was obtained, and the value of this ratio was then obtained by comparison with our sub-standards, the value of which we know to a very high accuracy. The result obtained was extremely satisfactory, as the value given by the two methods were in agreement to the third significant figure. Mr. Trotter.

In testing a resistance of this kind, although it is intended to carry, say 2,000 amperes, it is not necessary to put the full current through it, for such resistances generally have a very low temperature co-efficient, and it is enough, when using this differential method, to measure the current approximately. In one test we used 1860 amperes. The point is, not that the current is exactly known, nor that it is constant, but that the same current is passing through the two resistances. We have used the method with ratios of 1 : 1, 1 : 10, 1 : 100, and 1 : 400. The only defect at present is, that we have to use a Thomson galvanometer. We are substituting D'Arsonval galvanometers for our other Thomson galvanometers, in order to be secure from outside magnetic disturbances; and I hope that a differential D'Arsonval will be sufficiently sensitive for use with this most valuable method.

Mr. C. V. DRYSDALE: I do not think that there is a subject in the whole range of electrical testing, which is of such great importance at the present time, as that of the measurement of alternate-current power under various conditions, nor one that is so little understood. In Mr. Campbell's paper a number of most ingenious methods of measuring alternate-current power are given, but I think that I am right in saying that these methods have simply been introduced to avoid the use of a wattmeter, an instrument which seems to have fallen into disrepute since its inductive and other errors were pointed out many years ago. When these errors were recognised, other methods for the measurement of alternate-current power were sought for, resulting in the introduction of the three-ammeter and three-voltmeter tests. Even as far back as eight years ago, Prof. Fleming, in his important transformer measurements, came to the conclusion that the wattmeter, without metal cover, gave more reliable results than these other methods. Notwithstanding this opinion, other methods of a somewhat similar nature have been brought out from time to time, regardless, apparently, of any consideration as to the accuracy which can be expected from them. I should like to point out that it is quite easy to find out what accuracy may be expected of any test, and venture to think that it would greatly assist those who have to make power measurements, if the inventors of these tests would provide us with such information As an example I should like to take the three-voltmeter method, which Mr. Drysdale.

Mr Drysdale.

Mr. Campbell has modified in one or two ways, but without altering the theory of the test. The diagram below, Fig. A., shows the connections, where L is the inductive load, R the non-inductive resistance, V_1, V_2, and V_3 the three voltmeters.

Then we know that the power taken by the load

$$w = \frac{V_1^2 - V_2^2 - V_3^2}{2R}.$$

By simply differentiating this formula we have

$$\frac{dw}{w} = \frac{2V_1^2}{V_1^2 - V_2^2 - V_3^2} \frac{dV_1}{V_1} - \frac{2V_2^2}{V_1^2 - V_2^2 - V_3^2} \frac{dV_2}{V_2} - \frac{2V_3^2}{V_1^2 - V_2^2 - V_3^2} \frac{dV_3}{V_3}$$

from which we see that an error of 1 per cent. in V_1 would cause an error of

$$\frac{2V_1^2}{V_1^2 - V_2^2 - V_3^2}$$

in the power. By working this out in various cases I find that in the most favourable cases for accuracy, when the drop across the non-inductive resistance equals that across the load, an error of 1 per cent. in reading V_1 would cause an error of 22 per cent. in the power, if the power-factor of the load is 0·1. Mr. Campbell modifies the method by making

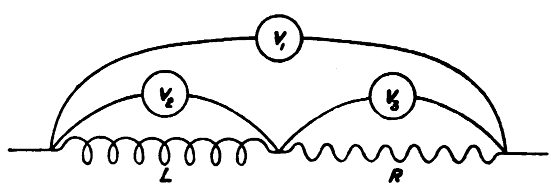

FIG. A.

the drop across the non-inductive resistance less in order to utilise the full potential of the mains on the load, which is of course an important advantage, but I have worked out the error in the case where the ratio of the P.Ds. on the load and resistance is 5 to 1, and I find that an error of 1 per cent. in reading V_1 would give an error of no less than 54 per cent. in the power at the same power-factor. Although Mr. Campbell claims an accuracy of 0·2 per cent. for his voltmeter, the error is then very serious, and with ordinary commercial instruments it can hardly be claimed that such tests are of any value whatever.

The best methods which Mr. Campbell puts forward in his paper are those under headings 3 and 4. Errors in the instrument readings are much less serious in these cases, but you will notice they involve the taking of two readings, not simultaneously, but one after the other. If you are using an electrostatic voltmeter with the degree of accuracy which Mr. Campbell claims, I should think that it would take a considerable fraction of a minute to get each reading accurately. Where you are taking the test on a perfectly steady load, this is not a very serious objection, but I should like Mr. Campbell to apply this method to a brake test of an alternate-current motor. When to the

difficulties of obtaining the best conditions of the test, you have added the getting of these readings with an unsteady brake, I do not think that the method is capable of any degree of accuracy. Mr. Drysdale.

I should like also to say a few words as to the errors which transformers introduce in these tests. In all the methods in Mr. Campbell's paper except No. 5 the inductive resistance is shunted by one of the coils of a transformer. That transformer may, and I believe it does, take an exceedingly small amount of current, but a very small amount of current in quadrature may cause a serious displacement of the phase difference between your inductive and non-inductive circuits, and I think Mr. Addenbrooke is in the right when he says that he has always been afraid to employ transformers in alternate-current tests.

As I stated at the outset, I believe that none of these methods would be necessary if satisfactory dynamometer or electrostatic wattmeters were available, and the prejudices against them removed. A direct-reading method with simple connections is surely to be preferred to one with complex connections, and involving troublesome calculations for every test. I think that Mr. Addenbrooke has shown in the case of the electrostatic wattmeter, and that I have shown for the dynamometer form of instrument, that the errors to which such instruments are liable are infinitesimal when properly designed. Messrs. Siemens have informed me that in their "precision wattmeters" the coefficient of self-induction of the shunt coil is 8·8 millihenrys, and that the non-inductive resistance used with them is 4,000 ohms when working on a 120-volt circuit. By a formula which I published recently I find that the maximum error in the power-factor due to this induction is only 0·0013, and this error is one that can easily be calculated and allowed for if necessary.

In my own form of wattmeter, designed for the laboratories of the Northampton Institute,[1] the self-induction of the shunt coil is only 7 millihenrys and the normal resistance 100,000 ohms, so that the error is absolutely negligible, while the range of the instrument is anything from 0·1 ampere to 100 amperes, and from 1 to 2000 volts, and its cost is less than that of an ordinary electrostatic voltmeter. Under these circumstances, I hardly think that any of the methods mentioned in the paper, beautiful and ingenious as they are, should ever be employed except in cases of emergency where a wattmeter is not available, and even then it would not take much more time to make up a wattmeter such as I suggest than to get all the retinue of apparatus together which would otherwise be required.

[*Communicated*]: Another point of great importance in Mr. Campbell's paper is the testing of alternate-current meters under fictitious loads. Here again the use of a wattmeter makes the test of much greater value. Mr. Campbell is at some pains in his connections to secure the same phase in his pressure and current circuits, but surely one of the most important points is to be able to test our meters under lagging loads as well. If we simply employ any ordinary transformers to give us our P.D. and current, without troubling about their induc-

[1] See the *Electrician*, March 15th, 1901.

Mr. Drysdale.

tances, and connect an accurate wattmeter so that its shunt and series coils are similarly connected to those of the meter under test, we can vary our lag to any extent by choking coils and standardise our meters quite conveniently under any conditions. Where extremely lagging loads are required we can derive our current and pressure from the different circuits of a two-phase supply if available. Of course it should be understood in all these tests that the wattmeter, if properly designed, requires no calibration, except a single standardisation at one point with continuous currents. In conclusion, I hope Mr. Campbell will excuse my having criticised his methods so adversely, but I think the thanks of the Institution are most cordially due to him for having brought forward such an important subject, and we must all admire the ingenuity which characterises his methods.

About Mr. Crawley's paper also I should just like to say a word. The differential galvanometer method, as modified by Mr. Crawley, gives unquestionably a most rapid and convenient method for the measurement and adjustment of resistances to a close degree of approximation. When, however, we require to standardise any resistance with the greatest accuracy and to determine its temperature variation, a replacement test such as the Carey-Foster method is always to be preferred, as Mr. Crawley admits in the case of higher resistances. Some time ago, when I had the honour to be associated with Mr. Crawley, I devised a simple modification of the Carey-Foster Bridge,[1] which rendered it suitable for all resistances, and which I have used with the most accurate results. I do not bring this forward as a substitute for Mr. Crawley's differential galvanometer, as I quite agree with him as to the simplicity and rapidity of his method, but for ultimate standardisation I think that either the Carey-Foster Bridge or the low resistance bridge of the Reichsanstalt should be employed.

Mr. Addenbrooke.

Mr. G. L. ADDENBROOKE (*communicated*): I wanted a system of measuring low resistances some time since for use in connection with the method of measuring alternating currents electrostatically, which I have been working on. When casting about for the best method, Mr. Crawley happened to mention to me the one he is describing to-night, and shortly afterwards Messrs. Nalder Bros. & Co. arranged one of the instruments for me.

I have had a fair experience in this class of work, and I must say that I have been delighted with the ease and simplicity with which Mr. Crawley's system works. I do not think that there is any other method which comes near it. At the same time, as this subject of measuring low resistances is brought forward, I would like to allude to a method which was described in the *Electrician* for December 24th, 1897, by Mr. R. H. Housman. My attention was drawn to this by Mr. J. Purrett (until lately of Messrs. Willans & Robinson, Limited), who told me that he used it effectively. As a handy means of measuring or calibrating low resistances when only a Wheatstone Bridge and a galvanometer are available, it seems to me superior to the methods usually given in the text-books.

Low resistances are so convenient for a number of purposes that I

[1] See the *Electrician*, October 5th, 1900.

think the profession owes Mr. Crawley its best thanks for bringing forward a method by which accurate results can so easily be obtained. Mr. Addenbrooke.

Coming now to Mr. Campbell's paper. Having succeeded in making an electrostatic voltmeter which will measure a drop of one volt easily within 1 per cent. and in which I have been able to get rid of the trouble with contact error, I am able to dispense with the transformer altogether which is shown in Mr. Campbell's second method. I have had in mind constantly the possibility of using transformers in some of the ways which Mr. Campbell suggests, and I think it is possible that they may be very useful within certain definite limits, particularly where the results obtained with them can be checked by some reliable method beforehand. But, whether rightly or wrongly, I have always been afraid of using them as a basis for accurate work without some means of checking their performances.

I regret that time does not permit me to deal with Mr. Campbell's suggestive paper in further detail, but I trust that the interest which is now being taken in alternating measurements will lead to a better understanding of alternating currents in this country, and will help to bring about greater confidence in their use.

Mr. ALEXANDER RUSSELL (*communicated*): It has been questioned whether it is allowable to suppose that the phase-difference between the primary and secondary volts of a transformer on light loads is very approximately 180 degrees. Methods and instruments which involve this assumption—and there are many in everyday use—are not regarded with favour by some electricians. Mr. Campbell's experiment (Method 6, 2), in which he found a phase-difference of 180°–0·15′ between the primary and secondary terminals of what is practically a toy transformer, shows that in many cases the assumption of practical opposition in phase is justifiable. Mr. Russell.

It can easily be proved theoretically that the assumption is sometimes allowable. Let e_1 and e_2 be the primary and secondary volts, i_1 and i_2, r_1 and r_2, n_1 and n_2 be the currents, resistances, and turns respectively; then if N be the flux in the core,

$$e_1 = r_1 i_1 + n_1 \frac{dN}{dt}$$

$$e_2 + r_2 i_2 = -n_2 \frac{dN}{dt}$$

$$\therefore \; e_1 + \frac{n_1}{n_2} e_2 = r_1 i_1 - \frac{n_1}{n_2} r_2 i_2 \quad . \; . \; . \; . \; . \; . \; . \quad (1)$$

Now on open secondary in a modern closed iron circuit commercial transformer the maximum value of e_1 is at least ten thousand times greater than the maximum value of $r_1 i_1$, and therefore in this case it is quite legitimate to write—

$$e_1 = -\frac{n_1}{n_2} e_2.$$

It follows that e_1 and e_2 are similar curves which are in exact opposition

Mr. Russell. in phase. When the maximum value of the right-hand side of (1) is less than the hundredth part of the maximum value of e_1, even if there is slight magnetic leakage, we can assume that e_1 and e_2 are similar curves which are almost in exact opposition in phase.

Similarly at heavy loads the resultant of the magnetising turns of the primary and secondary coils is a very small quantity compared to either of them, and hence in this case the primary and secondary current waves are nearly similar curves, whose phase-difference is nearly 180 degrees.

I would like to call attention to the first Appendix to Mr. Campbell's paper. The theorem there enunciated is, I think, entirely new and of great practical importance. Mr. Langdon-Davies some eight years ago explained to me how he got a circular rotating magnetic field by placing the field coils in his motor so that the angle between their planes was equal to the supplement of the angle of phase-difference between the currents in them. I did not then appreciate what Mr. Campbell has now shown, that we can always get a field which will produce a constant effective E.M.F. in a coil whose plane is perpendicular to the field, no matter what the shapes of the current waves are.

Suppose that we have two equal circular coils having a common diameter, and whose planes are inclined to one another at an angle a. If alternating currents flow in these coils it is useful to know how the effective value of the magnetic forces produced resolved along a line through the centre perpendicular to their common axis varies with the position of this line. Let f_1 and f_2 be the values of the magnetic forces along the axes of the coils, and let f be the resolved value of these forces along a line making an angle θ with f_1, then

$$f = f_1 \cos\theta + f_2 \cos(a - \theta).$$

Let F, F_1, and F_2 be the effective values of f, f_1, and f_2, and let ϕ be the angle of phase-difference between f_1 and f_2; then if F_1 is made equal to F_2 we have

$$F^2 = F_1^2 \left\{ \cos^2\theta + \cos^2(a-\theta) + 2\cos\theta\cos(a-\theta)\cos\phi \right\}$$

$$= F_1^2 \left\{ (\cos a + \cos\overline{a - 2\theta})(\cos a + \cos\phi) + \sin^2 a \right\}$$

Written in this form we see at once Mr. Campbell's result, namely, that F equals $F_1 \sin a$, and is consequently independent of θ when $\cos a + \cos\phi$ is zero, *i.e.*, when a equals $180^\circ - \phi$.

In the general case, F is a maximum when θ equals $\frac{a}{2}$ or $\frac{a}{2} + 180^\circ$, and is a minimum when θ is $90^\circ + \frac{a}{2}$ or $-90^\circ + \frac{a}{2}$. If we plot out a curve showing the values of F for various values of θ, we get a curve which is very similar to an ellipse.

The theorem can also be extended to three-phase theory, and as it has a direct bearing in practice I shall indicate the proof. Suppose that we have three equal cylindrical coils arranged round a circle at 120° apart, their axes all pointing to the centre of the circle. Let f_1, f_2, and f_3 be the strengths of the field produced at the centre by each when

they are connected to the mains of a three-phase system either in star or mesh fashion, then Mr. Russell.

$$f_1 + f_2 + f_3 = 0$$
$$\therefore F_1^2 = F_2^2 + F_3^2 + 2 F_2 F_3 \cos \phi_{2 \cdot 3},$$

where capital letters denote effective values and $\phi_{2 \cdot 3}$ is the angle of phase-difference between f_2 and f_3. If the currents be adjusted so that

$$F_1 = F_2 = F_3,$$

then $$\cos \phi_{2 \cdot 3} = -\tfrac{1}{2},$$
$$\therefore \phi_{2 \cdot 3} = 120^\circ.$$

Draw a line through the centre making an angle θ with f_1 and let the resolved magnetic force along this line be f, then

$$f = f_1 \cos \theta + f_2 \cos (\theta - 120^\circ) + f_3 \cos (\theta - 240^\circ),$$
$$\therefore F = \tfrac{3}{2} F_1.$$

Therefore F is independent of θ, and the current produced in a coil perpendicular to the rotating magnetic field is independent of the angular position of the coil.

In practical work, when we have iron in the cores of the coils, $f_1 + f_2 + f_3$ is not zero at every instant. In this case we can show that $\cos \phi_{2 \cdot 3} = -\frac{m}{2}$, where m is less than unity and from symmetry $\phi_{2 \cdot 3} = \phi_{3 \cdot 1} = \phi_{1 \cdot 2}$, hence

$$F = \frac{\sqrt{6 + 3m}}{2} F_1.$$

Therefore in this case also F is independent of θ.

It is very curious that in these cases, although both the magnitude and the angular velocity of the magnetic field are continually changing, yet so far as a test coil can judge it is isotropic. Professor Ernest Wilson has proved in the *Journal*, vol. xxviii. p. 331, that it is impossible to get a pure rotating field by means of two or three phase alternating currents except in the very special case when these currents follow the harmonic law.

I congratulate Mr. Crawley on having perfected such an elegant and useful method of measuring small resistances. He has done good service in calling the attention of electricians to the differential galvanometer. I have found that a well-made high-resistance differential galvanometer is not only useful for various tests such as measuring high inductances, etc., but it can be used also as a standard of capacity and hence can be used to measure exceedingly high resistances by the rate of loss of charge method. Suppose that A, B_1, B_2, and C are the four terminals of the two coils of a differential galvanometer; then if B_1 and B_2 are disconnected and a small voltage is applied between A and C, there will be a large throw of the needle due to the mutual electrostatic capacity of the coils. On short-circuiting A and C we get an equal throw in the reverse direction. Putting a condenser between B_1

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Mr. Russell. and B_2 we get an increased kick, putting it in series with the galvanometer a diminished kick, and so on. All the effects produced, which are very puzzling at first, can be explained by elementary theory, but the explanation necessitates hard thinking on the part of the student. In a galvanometer by Elliott Brothers, which I have used constantly for the last eleven years, the resistance of each coil is 3,500 ohms and the mutual capacity of the coils is 0·308 of a microfarad. It reflects great credit on its makers, as the insulation resistance between the coils is exceedingly high. Resistances can be measured on a bridge by this galvanometer without connecting B_1 and B_2 if the experimenter taps down the galvanometer key between each observation. If manufacturers will wind two coils of wire on a reel so that they can be used as an approximate standard non-inductive resistance, as two coils of known self inductances, as a known mutual inductance, as an approximate standard of capacity and as a high standard of insulation resistance, they will find that these coils will be much appreciated in physical laboratories and test rooms.

Mr. Fisher. Mr. W. C. Fisher (*communicated*): Having had no slight experience in the design and manufacture of differential galvanometers, reflecting and indicating, I can quite agree with Mr. Crawley as to the delightful *simplicity* attendant upon their use in the manner described by him. His paper is, however, deficient in one important respect; he gives no hint as to the *type* of instrument he would recommend. Now if the type of instrument employed is the ordinary Thompson, then the method suggested loses all its advantages, as there are few places where it can conveniently be employed, and with the spread of "tubes" and electric traction generally it will soon be relegated to, and find its home in, such wilds as South Kensington and Bushey Park. If, on the other hand, the type is of the moving coil or D'Arsonval pattern, will he tell us how he captured—that "De Wet" of all pattern differential instruments of this type—constancy of zero?

As to comparison of potentiometer and differential methods, having had experience of both I am not prepared to assign premier position to the differential. I can, of course, quite sympathise with Mr. Crawley's difficulty in commercially turning out 150-section potentiometers to compete with those having a slide wire and 15 sections; his remedy is obvious—ignore small boys and half-bricks—but, at the same time, calibration *can* be done by potentiometer as expeditiously as any other way and certainly more satisfactorily. Some twelve or eighteen months ago it was my misfortune to find two Fleming-pattern standard ohms destroyed by unaccountable electrolysis. Two new lengths of wire were taken, wound, annealed, and adjusted to a manganin standard in twenty minutes (timed out of curiosity); one of these was sent to the Board of Trade who reported no appreciable error, and from my knowledge of differentials I question whether they could break that record. As for accuracy, the Board of Trade gave the following figures for three manganin standards sent by purchasers for check values:—

Mr. Fisher.

$\frac{1}{10}$ Ohm.	Current.	1·5	3	6	9	12	15	Amps.
	Value.	0·0996	·0997	·0998	·1000	·1000	·1000	Ohm.
$\frac{1}{100}$ Ohm.	Current.	15	30	60	90	120	150	Amps.
	Value.	0·00999	·01000	·01000	0·1000	·00999	·00999	Ohm.
$\frac{1}{2000}$ Ohm.	Current.	150	300	600	900	1200	1500	Amps.
	Value.	0·000500	·000500	·000500	·000500	·000500	·000500	Ohm.

No great care was taken in adjustment. It was not known that they were to be sent to the Board of Trade. They were of ordinary stock pattern, turned out commercially.

The only supposed difficulty attendant upon potentiometer method is when at high current rates there is likely to be fluctuation between readings; but in effect this is inappreciable in the small interval of time that takes place. For some time there has been complaint at the ancient pattern standard ohms allowing but $\frac{1}{10}$th of an ampere standardising current. We now have advocated a comparatively small current in standards that *are* capable of taking more; of course it is purely a question of sensibility, and in that respect the differential possesses absolutely no advantage over the potentiometer, provided the latter is set out specially for the comparison of resistances.

The method described and illustrated in Fig. 6 was suggested by me five years ago for obtaining the resistances of carbon electrodes of over 200 square inches sectional area, with this difference, that the strip O—100 was shunted by a long wire of comparatively small diameter—so allowing the use of, say, a metre bridge—and materially lengthening the scale O—100.

Practically the whole question as to Differential *v.* Potentiometer amounts to this: in the first case you are dependent upon the behaviour of delicate apparatus and forces, and in the last you have mechanical excellence alone to contend with, and that can be made substantial as well as the forces employed. As a matter of fact, however, fair comparison can not be made unless the potentiometer, like the differential, is laid out for the particular job of low resistance tests and not, as at present, a "maid of all work."

Mr. M. M. Gillespie (*communicated*): I read with great interest Mr. Campbell's paper "On Test Room Methods of Alternate Current Measurement," and I feel sure such a paper will be greatly valued by many who, like myself, spend a great deal of their time on alternate current measurement. Mr. Gillespie.

Some five years ago, when the Westinghouse Company were having their laboratory reorganised for the testing of alternating current wattmeters, I had the pleasure of calibrating a great number of Shallenberger integrating wattmeters at Faraday House, and the Method No. 7 described by Mr. Campbell was the one we used to adjust these instruments for inductive circuits, and with very good results indeed. At the Westinghouse Company's laboratory we use a Kelvin quadrant electrometer connected as a wattmeter for adjusting alternating current wattmeters, and I remember at the time—when we got this Kelvin instrument set up—comparing some meters which had been adjusted

Mr. Gillespie.

on inductive loads at Faraday House by the method named, the results were very close. I would have liked Mr. Campbell to have described a little more fully some of the methods, still I feel certain many of us will find the paper a very useful one.

Professor Callendar.

Professor H. L. CALLENDAR (*communicated*): The writer had had some experience, which might be worth recording, of many of the thermal methods mentioned by Mr. Campbell. One of the simplest thermal methods, the Hot-wire Voltmeter, had long been familiar in the form in which the record or indication was obtained from the thermal expansion. The disadvantage of this method, in addition to its sluggishness, was that owing to the smallness of the expansion a large magnification became necessary, which involved great loss of power, so that errors frequently arose from friction. The zero was also liable to shift from a comparatively small strain in the wire. In spite of these defects the method was well known to be susceptible of considerable accuracy. The disadvantages of the method, such as they were, could be entirely obviated by employing the increase of resistance of a wire in place of its linear expansion. The increase of resistance of a pure metallic wire was several hundred times as great as its linear expansion, and could be more accurately measured, although the apparatus required was less simple. Employing the resistance method, it was unnecessary to subject the wire to tension or stress, and it was therefore possible to employ the finest filaments without risk of strain. At the same time the sensitiveness of the method was very greatly increased, and the waste of power in the voltmeter was reduced to a negligible quantity. The writer had exhibited a recording instrument of this class at the meeting of the British Association in 1898. The sensitive part was a loop of platinum wire 2 inches long and 0·001 inch diameter. The record was taken with a pen on a scale half an inch to the volt, reading from 100 to 120 volts (or any other range required), and could be read to a tenth of a volt with certainty. No doubt this degree of accuracy was quite unnecessary for many practical purposes, but with the advance of science it was probable that the need of precision would be more keenly felt in the future, and such methods might then find a wider field.

The writer had also applied Method 11, the Wheatstone Bridge, for obtaining a steady current for potentiometer purposes, under the name of a Potentiometer-Bridge-Rheostat. By employing sufficiently fine wires, and compensating for changes of external temperature, the method became very sensitive and accurate. This automatic regulation of the current was very convenient for a Recording Potentiometer, as it evaded the necessity of employing a standard cell to adjust the scale of the record. The apparatus, when suitably adjusted, might be connected to any storage cell with the certainty that the scale would not vary more than one or two parts in a thousand if the voltage of the cell was between 1·9 and 2·1 volts. It might even be used on a constant potential lighting circuit, if the range of variation did not exceed 5 per cent. up or down. By a suitable arrangement of resistances it was also possible to make the current through the bridge-wire, F H Fig. 12, vary inversely as the voltage on the circuit, so as to make the scale of the record vary directly as the volts. If the main current were taken

Professor Callendar.

through a suitable low-resistance shunt, the P.D. on which was balanced on the bridge-wire, the record could be obtained either in watts or amperes, according as the current through the bridge-wire was adjusted to vary inversely as the volts, or to be independent of the voltage. The writer had published two sample records taken by this method in the *Electrician*, September, 1898. In addition to the accuracy attainable by the application of the potentiometer method, this arrangement possessed the advantage of great flexibility, and could be adapted to cover a very wide range by merely changing the shunt or the voltmeter resistance. The same instrument had been used to record the E.M.F. of a thermo-couple on a scale of 1 inch to a thousandth of a volt, or the voltage in a power-house between 500 and 600. In the latter case the same instrument could be transformed by merely turning a switch so as to read in watts or amperes, with a range of 10,000 kilowatts.

About six years ago the writer had made a very careful test of a Thermal Current Standard, to balance at one ampere, constructed on a similar principle. It appeared to be nearly, if not quite, as good as a Kelvin current balance, but was distinctly inferior in accuracy to a good standard cell and a resistance. This was probably due to changes in the emissivity, which could not be entirely prevented even by hermetic sealing.

There could be no doubt that these thermal methods possessed great adaptability, and would repay further investigation. A great advantage was that they could in many cases be directly applied to alternating current work as well as continuous. The chief difficulty so far encountered had been that of getting instrument makers to understand the method of adjustment and compensation. Mr. Campbell was to be congratulated on the great progress he had made in the theory of these thermal methods of measurement, and the practical application would certainly follow as soon as engineers learned to appreciate the convenience of the methods and the accuracy attainable by their use.

Mr. Crawley.

Mr. C. W. S. CRAWLEY, in reply, said: I do not think there is anything which has been said in the discussion calling for a reply. There is one disclaimer I should like to make. Mr. Addenbrooke referred to it as my method. Some years after I began to employ it I found a reference to a somewhat similar use by Heaviside in 1873. All that I can claim is: to have brought forward a method which, if it has ever been used in practical work, has to all intents and purposes dropped out; to have added some practical details and to have adapted it to modern uses; and, I hope, to have shown that it is a most convenient and accurate one for every-day work.

Mr. Campbell.

Mr. ALBERT CAMPBELL, in reply, said: The first point raised by Mr. Glazebrook referred to the permanency of the nickel wires. The metal is modern nickel, and not the nickel of five or six years ago. It gives a very low resistivity, and is very nearly pure, although it is a commercial specimen. There is very little change, if any, in the nickel, if it is taken up to a red heat, and never again allowed to be so hot. So far as I have observed, one gets a repetition of results from time to time, but I do not think I have tested the point sufficiently. I have only used nickel as an example here because it was the cheapest suitable metal.

Mr. Campbell.

Platinum can be used, in fact some of the experiments were made with platinum, and it certainly can be carried to a conveniently high temperature without practically having any change in it. As to the use of a thermal standard of current, I do not know if I pointed out that that bridge is compensated for temperature, so that the temperature of the enclosure does not matter. The combination has to be standardised in the ordinary way by a Clark cell or silver voltameter, and it can only be taken as a secondary standard. As to Mr. Drysdale's remarks on some of my alternate-current methods, I have not put all of them forward as the general methods. I think that the method of transforming up from a low resistance to an electrostatic voltmeter, if you have a suitable transformer, is more convenient than a Kelvin balance. One can read the long-scale electrostatic instrument with great ease. It comes to rest in very much less than a minute, and one can read currents of all sizes with accuracy of perhaps one in a thousand. I think that must be of general use. As to the methods of measuring power which Mr. Drysdale criticised chiefly, I do not say that a wattmeter is not the best way. But how are you going to calibrate your wattmeter? I consider the method shown in Figure 8 one of the best methods of testing a wattmeter with inductive load. I think you must use a method like that in order to calibrate your wattmeters and to know that you are getting down to low power-factors. As to those which are like the 3-voltmeter method, I do not say that in most cases they are desirable, but you certainly cannot always have a wattmeter to measure all the kinds of loads that may turn up. I have sometimes had to measure the watts spent in the inductive series coil of a watt-hour meter for 200 amperes, and perhaps 0·2 of a volt. I scarcely think Mr. Drysdale's wattmeter would measure that load. One would require such a very wide range of wattmeters for all these cases. It is in the extreme cases like this, as I said at the beginning of my paper, that we want handy methods which are nearly as accurate as the standard methods and far more available. In an ordinary test-room one can usually find standard electrostatic voltmeters and resistance suitable. Of course one must be careful not to get cases with extreme errors, as Mr. Drysdale pointed out, but it is sometimes better even to have a small amount of error than no measurement at all. As to the difficulty with a varying load on an alternating motor, by using a proper electrostatic voltmeter with oil damping, and switching back and forward a number of times, the error is minimised.

On the motion of the PRESIDENT, a hearty vote of thanks was accorded to Mr. Crawley and Mr. Campbell for their papers.

The President.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Member:

Ralph Gooch Tyler.

Associate Members:

Percy Mayson Bennett.
Arthur Edgar Gott.
Jonathan Edward Hodgkin.
H. Tomlinson Lee.
William Y. Lewis.
William Alexander Moore.
John Purrett.
Charles Edwin Campbell Shawfield.

Associates:

Alfred Sydney Lyell Barnes.
Herbert John Dockrell, R.N.
John Britton Hyde.
Thomas McDonnell.
James Scott Pringle.
George Schultz.
Gerrard Edmund Wigram.

Students:

Walter Arnold Blackburn.
Norman C. Bridge.
Christopher James Hutchinson Clapham.
Arnold Hampden Fenton.
Joseph Goodman.
John William Griggs.
Churchill Knight.
Charles William Lund.
Arthur George Moore.
Eldin Swanzy Moulden.
Kenneth Wallace Sutherland.
Thomas Taylor Tucker.
Humphrey Guest Wightwick.

The Three Hundred and Sixty-Fourth Ordinary General Meeting was held at the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, May 2, 1901, Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on April 18, 1901, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that the list should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Associate Members—

Albert P. Pyne.	Alfred R. Sillar.

From the class of Students to that of Associates—

Percival Francis Crinks.	William Austin Toppin.

Messrs. W. W. Cook and E. Garton were appointed scrutineers of the ballot for the election of new members.

Donations to the Building Fund were announced as having been received since the last meeting from Messrs. W. Del Mar, Geo. Johnson, J. E. Stewart, and G. E. Wigram, to all of whom the thanks of the meeting were unanimously accorded.

The PRESIDENT: In accordance with Article 45, it is my duty to read to you the list of Council nominations for election at the Annual General Meeting—the election of Council and Honorary Officers for 1901–1902 :—

MEMBERS NOMINATED BY THE COUNCIL FOR OFFICE IN 1901-1902.

As President.

Nomination.	W. LANGDON.

As Vice-Presidents (4).

Remaining in Office.	R. K. GRAY.
New Nominations.	Major P. CARDEW, R.E. S. Z. DE FERRANTI. JOHN GAVEY.

Ordinary Members of Council (15).

Remaining in Office.	H. H. CUNYNGHAME, C.B. HENRY EDMUNDS. ROBERT HAMMOND. HUGO HIRST. J. E. KINGSBURY. A. J. LAWSON. R. PERCY SELLON. C. P. SPARKS.
New Nominations.	H. E. HARRISON. Lt.-Col. H. C. L. HOLDEN, R.A., F.R.S. The Hon. C. A. PARSONS, F.R.S. W. H. PATCHELL. J. H. RIDER. MARK ROBINSON. J. SWINBURNE.

Associate Members of Council (3).

Remaining in Office.	W. R. COOPER, M.A., B.Sc. R. W. WALLACE, K.C.
New Nomination.	W. DUDDELL.

As Hon. Auditors.

For Re-Election.	F. C. DANVERS. E. GARCKE.

As Hon. Treasurer.

For Re-Election.	Prof. W. E. AYRTON, F.R.S. (Past President).

As Hon. Solicitors.

For Re-Election.	Messrs. WILSON, BRISTOWS, & CARPMAEL.

The PRESIDENT: I have to announce that the Council has appointed a Committee to determine whether it can recommend the Council to take any action, and, if so, what

action, to assist the industry in connection with the matters dealt with in Mr. Madgen's recent paper.

The Committee is anxious to inquire impartially into the matter, and to hear the views that may be put forward on all sides of the question. It has therefore determined, with the sanction of the Council, to ask for evidence from gentlemen representing different interests or views, and to consider such evidence carefully. A procedure in many respects similar to that of a Parliamentary Committee will therefore be adopted, proof offered by members and others will be circulated among the members of the Committee before the meeting, and this proof will then be discussed with the gentlemen presenting it. In order that the mass of evidence, which it is hoped may thus be obtained, shall not be lost, shorthand notes will be taken of the proceedings at the meetings.

AN INSTRUMENT FOR MEASURING THE PERMEABILITY OF IRON AND STEEL.

By C. G. LAMB, M.A., B.Sc., Associate-Member; and MILES WALKER, B.A., Associate.

The instrument described in this paper has been designed to meet the demand for a simple, cheap, and reliable piece of apparatus for measuring the permeability of iron and steel. The authors have tried to construct an instrument which would be extremely simple to use, and whose calibration should be dependent on such principles as should render it incapable of alteration with time and with somewhat careless usage.

The principle adopted is that of balancing the reluctance of an air-gap against that of the specimen under test by means of altering the length of the air-gap. Since the reluctance of such an air-gap of given dimensions is invariable, the accuracy of an instrument based on this principle depends only on the accuracy with which the dimensions of the air-gap can be measured, and the delicacy with which the point of balance can be ascertained.

In order to fulfil both these conditions, the instrument, as first used, is made as shown in Fig. 1. The specimen to be tested consists of a bar, turned up to a definite diameter

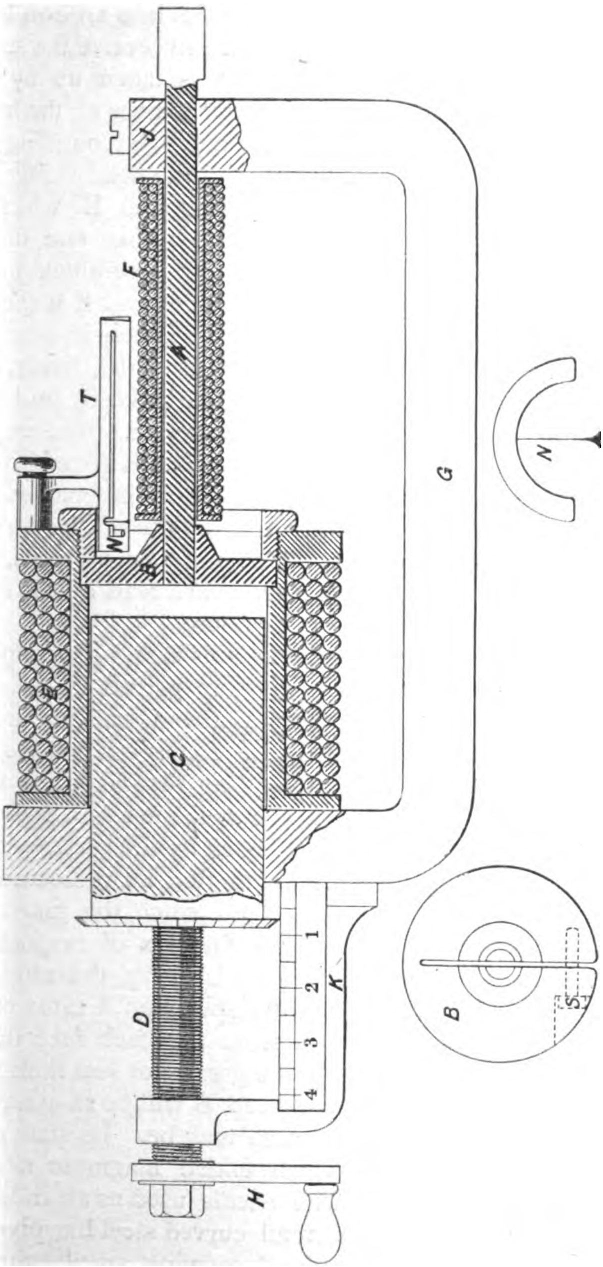

FIG. 1.

(which we have taken as three-eighths of an inch), and about seven inches long. One end of this fits into an iron head B, provided with a hole of the right size to receive the specimen. Any slight looseness in the fit is taken up by the screw *s*, which draws together the two halves of the head, this being almost severed by a saw cut. Surrounding the specimen is a magnetising coil F, and the head B fits into a recess turned in another magnetising coil E, which is wound on the adjustable air-gap. The other end of the specimen is fixed to the yoke-piece G by the block J and two set screws. Opposite the end of the head B is the flat face of an iron cylinder C, which is two inches in diameter and three and a half inches long. This slides freely, but with a good fit, through a hole in the yoke G, and can be moved parallel to its own axis by a screw D fixed rigidly to it, and working in a boss on the bracket K (fixed to the yoke G) by means of the handle H. This enables the operator very gradually to alter the length of the air-gap between B and the cylinder C. The number of turns, and fractions of a turn, made by the screw are read on the scale and graduated head shown in the figure.

In the instrument described, the coils E and F are wound with the same number of turns and are placed in series in such a manner that the magneto-motive forces on air-gap and specimen (which are in this case equal) act in the *same* direction—that is, they assist in creating the magnetic flux, the path of which lies through the specimen A, across the air-gap, along the cylinder C, and back by the yoke G to A. If the air-gap be so adjusted in length that its reluctance is equal to that of the specimen, then since the magneto-motive forces are the same for both, the flux of magnetism through each must be the same—that is to say, the whole of the lines of force coming from the specimen A must cross the air-gap, and none will escape from the back face of B. If, however, the reluctance of A be greater or less than that of the air-gap, the whole of the head B will be magnetised positively or negatively as the case may be. Its state may be indicated by means of a suspended magnetic needle placed in proximity to it. The needle used as an index is shown at N. It consists of a small curved steel bar pivoted on a jewel and needle point, and carrying an aluminium pointer. The latter is protected from air currents by means

of a brass tube T, provided with two windows to observe the position of the index. These windows are covered with a slip of mica pushed into the tube. The whole arrangement can be detached at will by a thumb-screw.

Although the instrument described above has an equal number of turns on both specimen and air-gap, this is not essential, and we can easily show that any ratio can be used. Consider a circuit made up of an air-gap with T_1 turns of wire on it, and a specimen with T_2 turns of wire, and let it be a perfect circuit—that is, let no flux issue from it into the surrounding air. Let ρ_1 and ρ_2 be the respective reluctances. When a current of A amperes is passing round the coil, and the same flux F is passing round the whole circuit (neglecting for the time any reluctance in the rest of the circuit) we must have

$$\rho_1 F = \frac{4\pi}{10} AT_1, \text{ and } \rho_2 F = \frac{4\pi}{10} AT_2, \text{ or } \frac{\rho_1}{\rho_2} = \frac{T_1}{T_2}$$

Hence by merely altering the ratio of the turns on the air-gap and specimen we can balance the reluctance of the specimens with different lengths of air-gap. This may be of advantage when we wish to measure the reluctance of specimens in the neighbourhood of their maximum permeability, or at very high inductions.

The operation of testing a specimen after it is turned to the right diameter is as follows: it is placed inside the coil F, and one end is inserted into the head B, which is then placed in the recess provided in the coil E, and fixed there by a thumb-screw as shown in the figure. The block H is then fixed in position, and the coils E and F being properly connected, are put in series with a reversing key, an adjustable resistance, an ammeter, and a few accumulator-cells. For the purpose of more finely adjusting the current we often prefer to connect the apparatus up, as shown in Fig. 2. The battery is placed in series with two resistances, conveniently about 10 ohms and 1 ohm, and the contact arms of these resistances are used to carry the current to the rest of the circuit; in fact, the current is supplied by a potential slide. This disposition, of course, entails some waste of current, but the advantage of being able very gradually to alter the current by small steps from zero to a maximum more than compensates for this disadvantage. This method

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will be found most convenient for all magnetic testing work. The amperemeter used is a Weston instrument reading to 1·5 amperes, but we have marked a second scale on it whose readings give directly the magnetising force, H, applied to the specimen, allowance having been made, in a manner afterwards briefly to be described, for the loss of magneto-motive force in the joints and yoke of the instrument. It is advisable before beginning a test to wipe out any magnetism that may be left in the instrument from a previous test by applying a fairly large magnetising force (say, H = 50), and reduce this through a series of reversals to

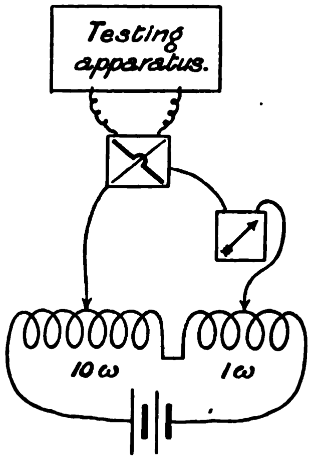
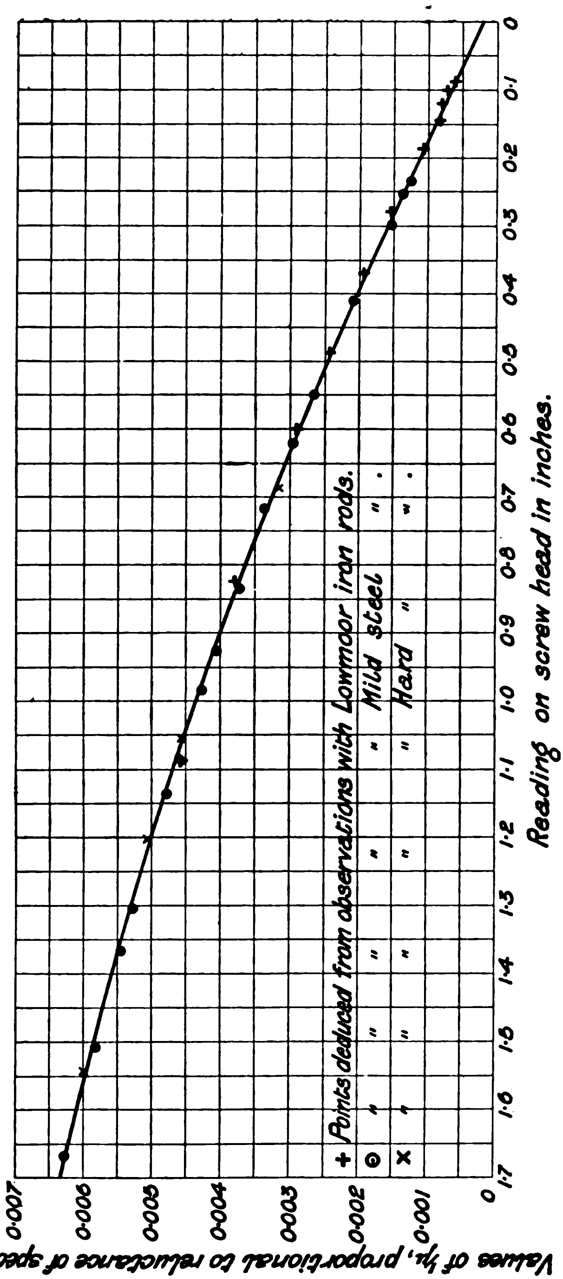


FIG. 2.

zero. The alternative method of connection enables this to be done with great convenience and accuracy. The current is then adjusted until the amperemeter reads a definite value, say H = 5. The index needle will now be found hard over to one side, and if the current be reversed it will go hard over to the other side. The handle is then turned to lengthen or shorten the air-gap until the needle points to a central position. It is well to reverse the current once or twice before taking the final position of the handle so as to establish well the cycle for that particular magnetising force. The reading of the scale is then taken, and the calibration curves supplied with the instrument give the permeability or its reciprocal without any calculation. It is found that

the movement of the needle enables the adjustment of the right length of a gap to be made with the greatest precision. An alteration of about $\frac{1}{1000}$th of an inch is sufficient to disturb the balance. The degree of sensitiveness has been attained by having a strongly magnetised needle placed close to the head B, and controlled by a magnet so as to be just in stable equilibrium. A magnetised needle suspended parallel and near to a vertical iron-plate is unstable, in the absence of outside controlling force, and the function of the magnet is to make the position just stable. It is adjusted in position to put the needle in its central position when the process of demagnetisation has been gone through, and before the test is actually commenced. In order that the readings of the instrument should be the same on reversal of the current, it is, of course, necessary that this process of demagnetisation should have been so carried out as to leave the circuit *completely* devoid of magnetism. This is not, in general, possible, and in practice great accuracy in the demagnetisation is not required. All that is necessary is to take readings for both directions of the current, and the mean of these is the true reading. This also greatly diminishes any effect of hysteresis in the yoke. It will be seen from Tables I. and II., which give the readings in a few tests made on Lowmoor iron and mild steel, that at fairly high inductions the two readings differ but little ; at low readings the demagnetisation adjustment is more important. In obtaining the readings given in Table I. some care was taken in this respect, and in adjusting the needle exactly central by the control magnet ; in the case of Table II. no special care was taken, and yet the readings were found to be quite reliable.

The scale-readings are found to be perfectly consistent for one specimen, and the important question arises whether the calibration curve is the same for specimens differing widely in permeability. The answer to that question is thoroughly satisfactory. Throughout the most important part of the magnetic curve, namely, the part dealing with the permeability at fairly high inductions, the readings of the instrument can be taken to measure the permeability within a fraction of 1 per cent. This was tested by obtaining the B-H curves of different specimens of material (viz., Lowmoor iron, mild steel, and hard steel) by Professor J. A.



0
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
1·1
1·2
1·3
1·4
1·5
1·6
1·7
Reading on screw head in inches.
0·007
0·006
0·005
0·004
0·003
0·002
0·001
0
Values of 1/μ, proportional to reluctance of specimen
+ Points deduced from observations with Lowmoor iron rods.
⊙ " " " " " Mild steel "
× " " " " " Hard " "

FIG. 3

Ewing's double-yoke method,[1] and calibrating the instrument in the method described below. Since the dimensions of the specimen and gap are determinate and fixed, it would evidently be possible to engrave the cylinder so as to give the permeability (or its inverse) directly, but we found it convenient, in the first place, to read from an arbitrary scale of inches and 1000ths, and connect with these quantities by calibration curves shown in Figs. 3 and 4. Tested by means of these specimens, no distinction could be made between the values obtained with the different specimens within the limits of error of other measurements made in

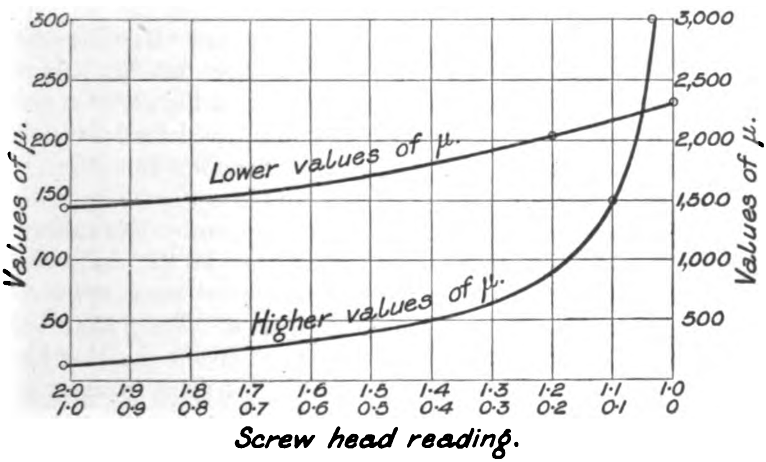


FIG. 4.

the observation. With regard to tests at low stages of the curve, it is doubtful if the use of small specimens is of much value for commercial purposes, since the behaviour of the iron under these low forces is so dependent on small accidents in its history that we can never be sure that the specimen represents the bulk; should the permeability under these conditions be required, the best method would be to build up an instrument from the material under test, and measure its permeability directly by a ballistic method. It is hence not a matter of great importance that at low inductions the end joints introduce an error varying with the material under test. The nature of this error may be

[1] Ewing on Magnetic Testing of Iron and Steel, Proc. Inst. C.E., vol. cxxi., part 4.

considered as follows: the joints and yoke introduce a certain reluctance, and to drive the flux through this requires a magnetomotive force which is approximately proportional to the flux. It was found, for instance, that for an induction per square centimetre of 15,000 in a specimen of Lowmoor iron about 9 ampere turns were required to overcome the joint and yoke resistance; the total ampere turns on the specimen was 298, so that 3 per cent. of the magnetomotive force was required for the joints and yoke. In a specimen of mild steel at the same flux-density the total ampere turns required was 350, so that the percentage expended on the yoke and joints was 2·7. In the graduation of the ampere meter we made an allowance of 2·85 per cent. at this part of the scale for the loss of ampere turns in the joint and yoke, so that the error at this point in reading H for either soft iron or mild steel was only of the order 0·15 per cent. At lower densities the effect of the joints is somewhat more important.

Details of the calibration of the instrument.—The calibration of the instrument was carried out in the following manner. Three pieces of Lowmoor iron were sawn off from the same bar and turned to gauge. They were not annealed, since in some previously used specimens that had been carefully annealed a question had arisen as to a change with time of the condition of the specimens. These were then tested in pairs by Ewing's double-yoke method. Two of the specimens were found in this way to agree very nearly indeed throughout the whole curve of magnetisation, while the third differed slightly in the early stages. One of the former pair was taken as standard, and was tested very carefully by the double-yoke method with the other as its return path. The ballistic galvanometer used to measure B was one of Crompton's midget type of D'Arsonvals. To eliminate any slight irregularity in the law of the instrument, it was calibrated relatively throughout its scale by successive throws from a standard air coil, the current being measured on a Weston ammeter previously calibrated by a potentiometer. In the double-yoke method the reluctance of the joints can be very accurately determined, and this enables a good estimate of the joint reluctance to be made in one instrument when the standard specimen was put in place. There are then two methods of arriving at the value

of H in the specimen when any measured current is passing round the magnetic coil. The first method, which was most accurate at high flux-densities when a large change in H makes but a small change in B, is to take the total magnetomotive force produced by the magnetising coil, and to deduct the known small magnetomotive force required for the joints, &c., and divided by the effective length of the specimen. The second method, which was relied on at lower flux-densities, where the joint-effect might be expected to be most variable in relation to the reluctance of the specimen, is to measure B in the sample by means of a search coil, and deduce the corresponding value of H from the calibration curve of the specimen. The two methods agree well between themselves at these points where they can be both applied. In this way a curve was made connecting the current in the magnetising coil of the instrument, and the value of H applied to the specimen when the instrument is properly balanced. By means of this curve a second scale was marked on the Weston ammeter on which the H can be directly read off. The correction is the same for any instrument made of the same dimensions, and hence has only to be determined once for all for any set. The readings of the screw head were now taken for various values of H, and a curve was plotted with length of air-gap as abscissa and $1/\mu$ as ordinate. This curve is given in Fig. 3. It will be seen that this curve begins with a straight line part pointing a little beyond the zero point, which means that with zero air-gap there is still some reluctance due to joints and yoke. As the air-gap is lengthened, the reluctance is at first increased proportionately, but as the gap gets longer still the field spreads more sideways, and a more than proportional increase in length is required to produce the same result in air-gap reluctance. A calculation of the reluctance of the air-gap when quite short gives a value agreeing exactly with the reluctance of the specimen as determined by the double-yoke method.

After this curve had been obtained for Lowmoor iron, a similar test was carried out with rods of mild steel, and it was found that the curve connecting air-gap length and 1μ (see Fig. 3) was the same as that for the Lowmoor iron. Two specimens of hard steel were then similarly dealt with, and the curve was further extended by this means. The

TABLE I.

Lowmoor Iron.

Current in Coil in Amperes.	H	B	$\frac{1}{\mu} \times 10^{-3}$	Length of Air-gap in Inches.		
				Readings with current in each direction.		Mean Reading.
0·03	1·42	1,180	1·20	0·204	0·205	0·205
0·04	1·88	2,100	0·89	0·129	0·139	0·135
0·05	2·32	3,400	0·68	0·097	0·103	0·100
0·06	2·78	4,500	0·62	0·089	0·091	0·090
0·08	3·68	6,450	0·57	0·079	0·083	0·081
0·10	4·58	7,950	0·58	0·080	0·082	0·081
0·15	6·95	10,550	0·66	0·098	0·101	0·100
0·20	9·35	12,000	0·78	0·123	0·123	0·123
0·30	14·30	13,750	1·04	0·183	0·185	0·184
0·40	19·20	14,620	1·31	0·230	0·235	0·233
0·50	24·20	15,210	1·60	0·300	0·300	0·300
0·60	29·50	15,600	1·90	0·363	0·363	0·363
0·80	39·20	16,050	2·45	0·500	0·500	0·500
1·00	49·20	16,350	3·03	0·643	0·643	0·643
1·10	55·00	16,600	3·33	0·710	0·720	0·715
1·15	56·50	16,660	3·38	0·750	0·750	0·750
1·20	59·20	16,700	3·55	0·780	0·790	0·785
1·30	64·20	16,800	3·84	0·851	0·867	0·859
1·40	69·10	16,950	4·10	0·935	0·945	0·940

TABLE II.

Mild Steel.

Current in Coil in Amperes.	H	B	$\frac{1}{\mu} \times 10^{-3}$	Length of Air-gap in Inches.		
				Readings with current in each direction.		Mean Reading.
0·04	1·97	388	5·08	1·065	1·120	1·093
0·06	2·95	738	4·00	0·766	0·914	0·840
0·08	3·92	1,340	2·93	0·576	0·617	0·597
0·10	4·86	2,235	2·17	0·385	0·425	0·410
0·15	7·17	5,280	1·36	0·245	0·245	0·245
0·20	9·50	7,550	1·26	0·228	0·227	0·228
0·30	14·30	10,550	1·35	0·253	0·246	0·250
0·40	19·30	12,310	1·56	0·300	0·292	0·296
0·60	29·10	14,120	2·03	0·420	0·412	0·416
0·80	39·10	15,020	2·60	0·552	0·548	0·550
1·00	49·10	15,650	3·14	0·692	0·685	0·689
1·20	59·10	16,000	3·70	0·836	0·828	0·832
1·40	69·10	16,350	4·23	0·984	0·981	0·983
1·60	79·10	16,600	4·77	1·136	1·133	1·135
1·80	89·00	16,900	5·27	1·308	1·302	1·305
2·00	99·00	17,100	5·79	1·518	1·504	1·511

calibration of the instrument as a measurer of μ was then drawn in the following way. The first part of Fig. 3 was taken as linear, and the reciprocals of the ordinates of this curve were taken as the ordinates of Fig. 4; the rest of the curve was plotted by taking the reciprocals of the curve in Fig. 3. For many purposes, however, the curve in Fig. 3 is itself the more useful.

Mr. S. EVERSHED: I think the last occasion on which we had an instrument of this kind brought before us was at a meeting some years ago, when Professor Ewing described an instrument for the same purpose, by which the reluctance of the sample was measured inferentially by the force necessary to remove it from its place in a magnetic circuit. I ventured at that time to make some perhaps unfavourable criticisms on Professor Ewing's instrument; and I may say I feel to some extent justified, because we have here to-night, coming from Cambridge, a much better instrument; in fact, it seems to me to be the first instrument based on the correct principle, comparing the reluctance of an indefinite thing with such a very definite thing as an air-gap. I congratulate the writers of the paper on the very simple way in which they have carried out the idea; but I should like to suggest to them that other methods of varying the reluctance of an air-gap might be tried with advantage. In particular I would suggest, although I do not know how it is to be applied to the instrument before us, that two flat plates of iron capable of motion in parallel planes and keeping the air-gap constant, might prove of some advantage, because it would have a straight line law over a much longer range. I have only used that type of air-gap in electromagnets, where it has the great advantage that the force can be calculated. The reason for that is that the fringe around, which does not go through what one may call the geometrical air-gap, is constant when you have two surfaces moving in parallel planes. It is constant very much in the same way as the electrostatic leakage from a Thomson electrostatic voltmeter is constant. I only suggest this as a possible way in which the authors' very ingenious instrument could have its range enormously extended. I cannot say that I have ever myself done anything in the direction of making an instrument for measuring the reluctance of iron. I have been more interested in measuring the qualities of magnetic steel; and there I must confess to having failed in devising any sort of instrument which would be fit for commercial purposes. All instruments seem to me to fail in one particular, namely, that you cannot easily prepare samples for them; you want the instrument built to fit the particular kind of steel or iron which you have to test. If you buy your iron or steel in bars, the instrument ought to be capable of dealing with short lengths of those bars. I can quite understand, for instance, that a manufacturer of dynamos who bought steel castings would like to test each individual casting before machining it. Great expense is incurred in machining and casting; and it is somewhat disheartening if, afterwards, the casting turns out badly. It would be Mr. Evershed.

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0·06	2·78	4,500	0·62	0·089	0·091	0·090
0·08	3·68	6,450	0·57	0·079	0·083	0·081
0·10	4·58	7,950	0·58	0·080	0·082	0·081
0·15	6·95	10,550	0·66	0·098	0·101	0·100
0·20	9·35	12,000	0·78	0·123	0·123	0·123
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0·50	24·20	15,210	1·60	0·300	0·300	0·300
0·60	29·50	15,600	1·90	0·363	0·363	0·363
0·80	39·20	16,050	2·45	0·500	0·500	0·500
1·00	49·20	16,350	3·03	0·643	0·643	0·643
1·10	55·00	16,600	3·33	0·710	0·720	0·715
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0·10	4·86	2,235	2·17	0·385	0·425	0·410
0·15	7·17	5,280	1·36	0·245	0·245	0·245
0·20	9·50	7,550	1·26	0·228	0·227	0·228
0·30	14·30	10,550	1·35	0·253	0·246	0·250
0·40	19·30	12,310	1·56	0·300	0·292	0·296
0·60	29·10	14,120	2·03	0·420	0·412	0·416
0·80	39·10	15,020	2·60	0·552	0·548	0·550
1·00	49·10	15,650	3·14	0·692	0·685	0·689
1·20	59·10	16,000	3·70	0·836	0·828	0·832
1·40	69·10	16,350	4·23	0·984	0·981	0·983
1·60	79·10	16,600	4·77	1·136	1·133	1·135
1·80	89·00	16,900	5·27	1·308	1·302	1·305
2·00	99·00	17,100	5·79	1·518	1·504	1·511

calibration of the instrument as a measurer of μ was then drawn in the following way. The first part of Fig. 3 was taken as linear, and the reciprocals of the ordinates of this curve were taken as the ordinates of Fig. 4; the rest of the curve was plotted by taking the reciprocals of the curve in Fig. 3. For many purposes, however, the curve in Fig. 3 is itself the more useful.

Mr. S. EVERSHED: I think the last occasion on which we had an instrument of this kind brought before us was at a meeting some years ago, when Professor Ewing described an instrument for the same purpose, by which the reluctance of the sample was measured inferentially by the force necessary to remove it from its place in a magnetic circuit. I ventured at that time to make some perhaps unfavourable criticisms on Professor Ewing's instrument; and I may say I feel to some extent justified, because we have here to-night, coming from Cambridge, a much better instrument; in fact, it seems to me to be the first instrument based on the correct principle, comparing the reluctance of an indefinite thing with such a very definite thing as an air-gap. I congratulate the writers of the paper on the very simple way in which they have carried out the idea; but I should like to suggest to them that other methods of varying the reluctance of an air-gap might be tried with advantage. In particular I would suggest, although I do not know how it is to be applied to the instrument before us, that two flat plates of iron capable of motion in parallel planes and keeping the air-gap constant, might prove of some advantage, because it would have a straight line law over a much longer range. I have only used that type of air-gap in electro-magnets, where it has the great advantage that the force can be calculated. The reason for that is that the fringe around, which does not go through what one may call the geometrical air-gap, is constant when you have two surfaces moving in parallel planes. It is constant very much in the same way as the electrostatic leakage from a Thomson electrostatic voltmeter is constant. I only suggest this as a possible way in which the authors' very ingenious instrument could have its range enormously extended. I cannot say that I have ever myself done anything in the direction of making an instrument for measuring the reluctance of iron. I have been more interested in measuring the qualities of magnetic steel; and there I must confess to having failed in devising any sort of instrument which would be fit for commercial purposes. All instruments seem to me to fail in one particular, namely, that you cannot easily prepare samples for them; you want the instrument built to fit the particular kind of steel or iron which you have to test. If you buy your iron or steel in bars, the instrument ought to be capable of dealing with short lengths of those bars. I can quite understand, for instance, that a manufacturer of dynamos who bought steel castings would like to test each individual casting before machining it. Great expense is incurred in machining and casting; and it is somewhat disheartening if, afterwards, the casting turns out badly. It would be

Mr. Evershed.

Mr. Evershed. much better if we could get an instrument that would test the iron in bulk. I think this point was touched upon by Mr. Mordey in the discussion on Professor Ewing's instrument; and I only mention it now in the hope that the writers of the paper will be able to bring us some day an instrument which will do in bulk what this does for samples.

Mr. Esson. Mr. W. B. Esson: Might I ask if the instrument is in the market? I observe Mr. Lamb describes the method of using the tester, from which it appears that, in order to work the instrument, you have to arrange a good deal of apparatus in the laboratory. What we want is something we can get into a small box, with the battery complete, so that we can take it to the bench and, by turning a handle or depressing a key, get a reading without any further trouble.

Mr. Hammond. Mr. R. Hammond: For many years of my life I was very closely connected with the manufacture of iron and steel. My thoughts were then directed to the various mixtures that had to go into the blast furnace, and in the Siemens-Martin furnace for the manufacture of steel. I have often been struck with the slight attention which has been given to the fact of how varied must be every brand of steel that issues even from the same works. Those who have to do with the manufacture of iron and steel know how the ores dug from the earth may vary though they have come from the same mines. I had great parcels of ore, many hundreds of tons at a time, from the Bilbao district; they were all carefully analysed, and we very rarely got a parcel of iron ore which was all of the same quality. Then the coke used in the furnace varied also, with the result that the finished steel also varied slightly, though you might buy it always from the same firm. What I wished to emphasise was the immense importance of the authors of this paper turning their attention to the testing of iron in bulk, and not to be contented with an instrument that tests only a small sample, because the practical man, like Mr. Esson, wants constantly to apply the test, even though his steel is supplied to him always from the same works. This is an instrument which is in the right direction; but we want an instrument that will deal with iron in bulk rather than with samples.

Mr. Drysdale. Mr. C. V. Drysdale: The instrument which Messrs. Lamb and Walker have shown us this evening adds yet another to the long list of beautiful instruments for the testing of the magnetic qualities of iron and steel which have emanated from Cambridge, and it is certainly not the least interesting or perfect of them. The balancing of the reluctance of the test specimen against so definite a thing as an air-gap is certainly a great advance over the methods which involve the use of a previously standarised specimen. It seems a pity, however, that in making this advance over the ordinary comparison tests that Messrs. Lamb and Walker have not been able to produce an instrument which is absolutely independent of previous calibrations. It is not easy to criticise an instrument of this kind without having had a considerable practical experience with it, but at first sight it would appear that by increasing the size of the yoke and paying special attention to the design of the contracts an absolute instrument might have been

Mr. Drysdale.

produced. I presume, however, that Messrs. Lamb and Walker have given attention to this point, and have found it impossible to attain such a result.

I venture to think that any one who has had much experience in the testing of the magnetic qualities of iron would always greatly prefer not to have to depend upon a calibration curve issued with the instrument, however permanent its construction may be. If this instrument is made commercially, and the calibrations are performed by the inventors themselves, every one would have confidence in them, but it is another thing if the calibration is to be performed by the manufacturer, and the instrument does not, unfortunately, lend itself well to a check by any independent method.

Another point I would like to ask the authors of the paper is whether they consider that the parts of the instruments can be so standardised that the same calibration would do for all the instruments. If the yoke and magnetic contacts were made heavier as suggested above, it seems to me that this might be the case; but where the reluctance of the yoke bears an appreciable proportion to that of the specimen, as it appears to do in the instrument shown, I question whether this would be so. It would of course greatly reduce the cost of the instruments if they had not to be individually calibrated.

A feature which seems to somewhat limit the use of the instrument is the reluctance of the air-gap, which would apparently prevent a high flux density being reached in the specimen without an unduly large magnetising force. I do not notice in the paper that anything is said as to the maximum induction density obtainable.

A further point which appears to me a somewhat serious one is that, as the permeability of the specimen increases, the air-gap has to be reduced to produce balance. At a permeability of 2,500, for instance, it would appear from the curve in Fig. 4 that the reading on the screw-head is only 0·04. I have not gone into the matter sufficiently to see to what accuracy the reading can be taken, but it seems disadvantageous at first sight that the readings of the highest permeability, which are generally required with the greatest accuracy, should be liable to the greatest error owing to the smallness of the reading.

I should like to mention a matter which is of the utmost importance as affecting the whole question of the testing of magnetic iron or steel: that of the nature of the cyclic operations to which the specimen is subjected. In every instrument for the testing of magnetic qualities which we have had up to the present, the specimen is subjected to an alternating magnetic stress, but in a large number of instances in practice the iron is traversed by a rotating magnetic field. This is, for instance, the case in dynamo armatures, in the stators and rotors of polyphase machines, and in polyphase converters.

I have recently been giving a considerable amount of attention to the testing of iron in rotating fields, and have devised two or three methods by which the B. H. Cycle can be obtained under these conditions. The cycles so obtained are absolutely different from those obtained in alternating fields, and I would suggest that in future any instruments which are brought forward for the testing of the magnetic

Mr. Drysdale.

qualities of iron or steel should be designed with this point in view, although of course it is not by any means so easy a matter to investigate as the ordinary alternating cycle. The importance, however, of this matter cannot be overrated, as is shown by the results as to hysteresis loss in rotating fields of Professor Francis Baily. Professor Baily has shown that the hysteresis loss of iron in a rotating field may be 50 per cent. higher or very much lower at different induction densities than that of the same specimen in an alternating field. So far as I am aware, dynamo builders still design their machines, using the ordinary Steinmetz formula for the calculation of the hysteresis loss. This formula is absolutely inapplicable to rotating fields, and it is to be hoped that in future we shall have instruments capable of easily testing our magnetic materials under the actual conditions in which they are used.

In conclusion I should like to congratulate Messrs. Lamb and Walker on the portability and self-contained nature of the instrument they have produced. It appears to be a considerable advance in this respect upon most of the ponderous permeameters which we have been accustomed to use.

Mr. Lamb.

Mr. C. G. Lamb (in reply): Mr. Evershed's point is one we have considered; but it was found difficult to make an instrument of the sort he mentions. It may be possible to overcome that difficulty later on. In this case the range can be extended by having a different number of windings on specimen and gap. The question of testing cast-steel in bulk is a most difficult one, but I believe that, up to the present, all methods have proved impracticable when tried on steel in bulk. It is a very important question, and it must be very seriously gone into. In reply to Mr. Esson's query, the instrument is not yet in the market, but will shortly be so. I think if Mr. Esson tries this instrument he will find it very simple. It does not claim to be a more accurate instrument than Professor Ewing's magnetic bridge, but we think it is more simple, and more convenient in operation.

On the motion of the President, the thanks of the meeting were unanimously accorded to Messrs. C. G. Lamb and Miles Walker for their paper.

A WATT-HOUR METER.

By Frank Holden, Member.

One of the earliest schemes for the measurement of ampere- or watt-hours was to have an ampere- or watt-meter, or, commonly, something apparently assumed to be one or the other, to indicate a distance or angle proportional to the amperes or watts, and, combined with this instrument, an arrangement for recording this angle or distance, and making a summation of the records. The final sum would, with a perfect instrument of this kind, be

proportional to ampere- or watt-hours for the period during which the summation took place, at least very closely on commercial circuits of almost any character if the instrument were allowed to record for a considerable time.

This is true for the reason that, while a considerable percentage of the individual readings may be in error, yet when a large number of these readings are made, these errors practically cancel out, as positive and negative errors of each particular size are equally likely to occur.

An examination of almost every if not every meter of this type shows that it either had an apparatus not sufficiently accurate in indicating the angle or length propor-

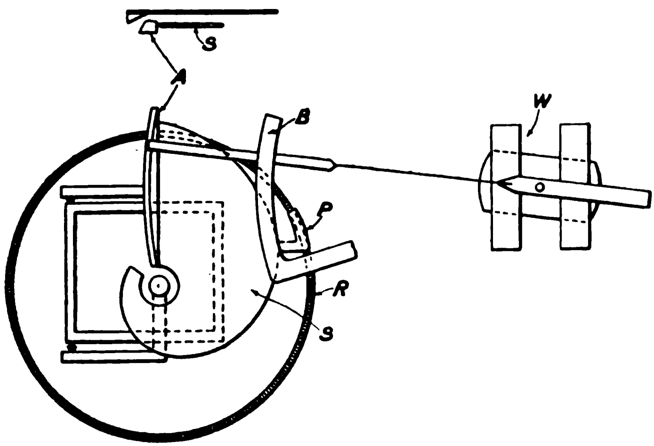

FIG. 1.

tional to the watts, or was deficient in means for recording the same, even were it correctly indicated, and not uncommonly there was trouble in both respects. In addition to these difficulties, there was commonly an electrically-wound clock that would not work for any extended period of time.

The meter which is the chief subject of this paper does not, perhaps, in strictness, belong to this class, but it more resembles these meters than any others that have been heretofore described. For the purpose of comparison, and for illustrating how this idea has been carried into practice heretofore, one of the most intelligently designed and successful of these meters, the Frager, will be described. It is shown diagrammatically in Fig. 1.

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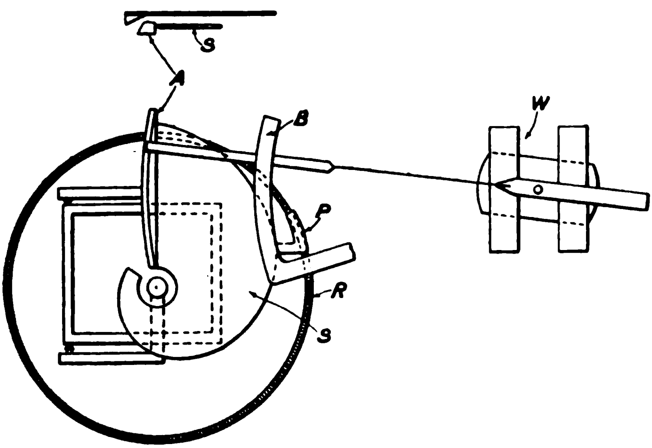

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In this figure, "W" is a watt dynamometer, the fine wire coil of which, suspended by a wire, carries a pointer, the end of which moves over the sheet metal snail or spiral "S."

An electrically-driven clock device uniformly rotates the vertical shaft carrying the snail, which makes one revolution every two to five minutes, depending on the size of the meter. With this also rotates a pawl, "P," which lies over the circular rack "R," which is geared to the indicating dials.

The snail revolves until the wedge at the end of the pointer meets the metallic arc, when the pointer end with the wedge is raised until the pointer is locked by being pressed upward against the milled under-surface of a bridge piece "B," under which it moves freely until the recording operations begin.

In time, the pointer end passes over the radial edge of "A," which also revolves, and, dropping on to the snail, depresses it, causing the pawl "P" to engage the rack, when the latter begins to revolve with the snail, and continues to rotate until the pointer passes over the edge of the snail, when the latter raises and releases the pawl. The angle of rotation depends on the angle of the arc traced by the pointer on the snail, and this angle is dependent on the shape of the bounding curve and the position of the pointer just before and during the making of the record. It is evident that, by properly shaping the bounding curve of the snail, this instrument could be made to indicate watt-hours under ideal conditions.

Taking into consideration the length of the pointer, 23 cm., and one's general experience with reading of instruments at zero, it does not seem likely that a reading of the pointer high or low of 1·5 mm. would be other than common. The length indicated by the pointer on the circular edge of "A" at full load is 76 mm., so this would mean an error of 2 per cent. at full load, 8 per cent. at quarter, 20 per cent. at one-tenth, and 40 per cent. at one-twentieth load; and a displacement of even 0·7 mm. would mean errors nearly as great as one-half these values.

Another source of error is in recording the deflection of the pointer, but in this particular instrument the error in doing this must be very slight, as the length of the arc

traced on the snail by the pointer when the load is as low as 2 per cent. of the full load is 10 mm., which could be recorded on the circular rack within 2 or 3 per cent. without necessitating too great structural refinement. When the load is double this, the arc on the snail becomes 20 mm. long, which, with the same refinement, would be measured within about 1 per cent., while above this the errors would certainly be negligible.

As there are a finite number of teeth, it follows that

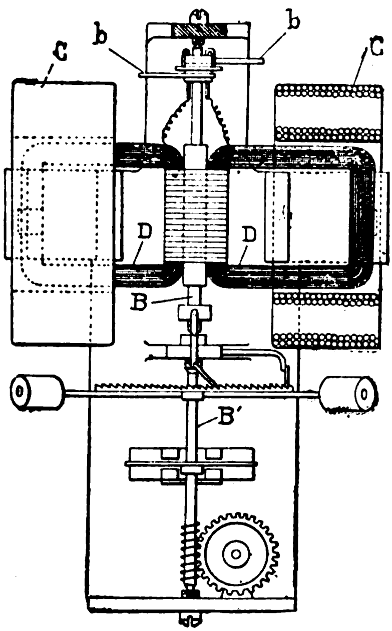

FIG. 2.

the distance moved by the pawls engaging the rack will not, in general, be an exact multiple of the space of one tooth of the rack, so that, in general, each record would be too low by some fraction of one tooth. But the error from this source may be eliminated by setting the pointer to read a little high at zero.

The fatal feature of this then, as a measuring instrument, would appear to be the impossibility of getting sufficiently accurate reading at low loads with so short scale as 76 mm.,

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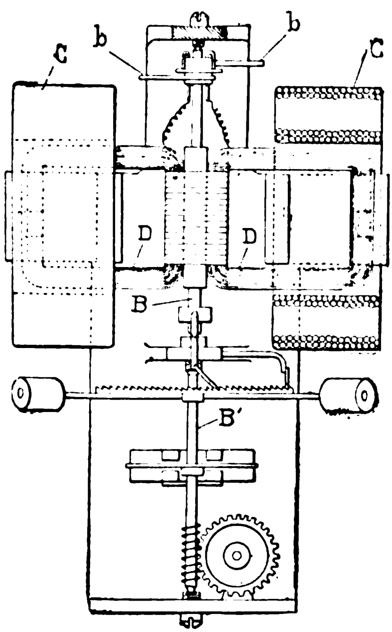

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and this has been the general failing of all instruments of this class.

Instruments of this type have, in the past, been so uniformly unsuccessful and short-lived, that it would seem a most unpromising field in which to work. However, they have for the most part, if not always, failed for very specific defects in either the clock-winding or measuring part, which it seems one could have foretold as being fatal ones; at least, one can see it plainly now.

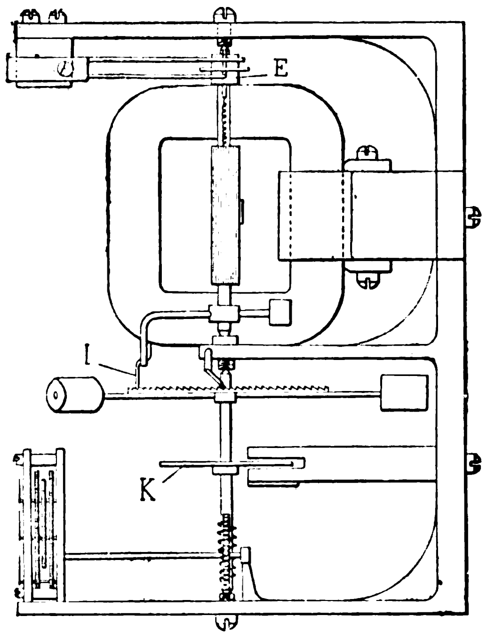

FIG. 3.

In the meter to be described, there has been an attempt at avoiding these defects by what are, in so far as the writer knows, new constructions, both in the clock-winding and the measuring mechanism.

The measuring part of this meter is shown diagrammatically in Figs. 2, 3, and 4, in which "C, C" are the main current coils, partly enclosing the shunt coils "D, D," which are mounted on the vertical axis "B." In the construction as shown here, it was intended to connect the coils astatically, so as to avoid any disturbing effect of the

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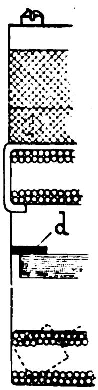

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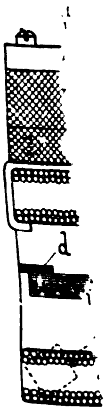

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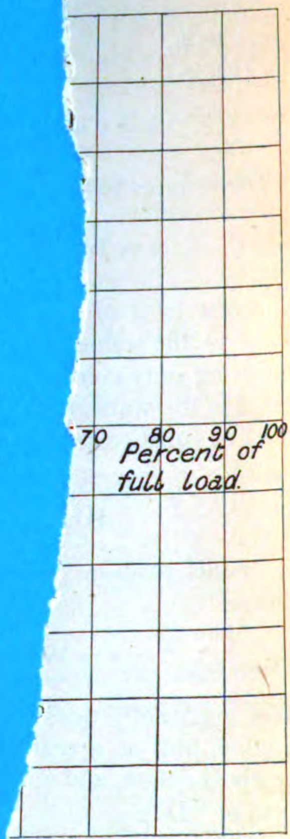

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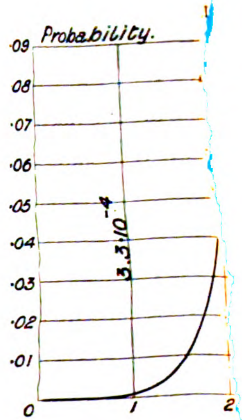

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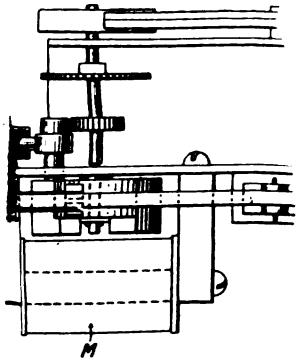

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Mr. Evershed.

It may quite possibly require some "man-power" to keep it in working order. I think probably all clock meters will. I found it very difficult to classify Mr. Holden's meter. We are quite accustomed, or were quite accustomed, to the idea of "feeler" meters, of which the Frager meter may be taken as a type; but I cannot help thinking that what Mr. Holden has said about the Frager meter may be regarded as a sort of funeral oration for all feeler meters. What he says is, perhaps, a little misleading, because he rather implies that his own meter belongs to that class, whereas it is really based on a totally different principle. In one sense all meters are motor meters; and all you really have to do is to drive the counting mechanism. In most meters you have incidentally to drive a lot of other things. For example, there is one meter in which the current drives an escapement brake and at the same time varies the period of the escapement. Another, in which there are two motors with escapement brakes going at slightly different rates, their relative periods being controlled by the watts: that is the Aron meter. Then there is a very curious type of motor meter—I do not know whether it has ever been properly described—in which you cause a motor to carry buckets full of something (I do not know what) from one plate to another plate, and tip the buckets out when they get to the other side—a sort of endless-chain arrangement. The quantity of stuff delivered by the buckets is proportional to the current, and all you have to do is to weigh it or measure its volume. We call the affair an electrolytic meter, but it is only an electric motor devised by nature. The electrolysis motor only appears to be extremely simple because you cannot see all the wheels.

Finally, we have the simple motor meter, in which an ordinary electric motor works against a Fouçault-current brake; and, in my opinion, that is the simplest meter of all. I naturally think so now, because, as you know, I have pinned my faith to it; but I pinned my faith to this type of meter long before I devised the particular example which I described to you last year. I think that meters containing clocks which close contacts, and so on, are only devised to avoid the supposed difficulty of making the commutator of a meter work sparklessly and without friction for long periods; and also to get rid of the friction of an ordinary motor. Those two difficulties did not, years ago, seem to me to be absolutely insuperable; and I have now the best of reasons for believing that they are not so. As a matter of fact, I see no essential difference between making and breaking a contact by means of a clock, and making and breaking a contact in a commutator, except that when you make and break by means of a clock you probably get a spark, and when you make and break by means of a commutator you can easily avoid serious sparking. When you contrast any of the meters containing clocks which make and break circuits, and in that way inferentially measure the electrical power being supplied, with the plain motor meter driving a brake, you are at once struck with the fact that the ordinary motor meter has only one moving part; and if that part can only be made properly, it should give very much less trouble and require very much less attention than a meter containing a number of

Mr. Evershed.

moving parts such as a clock meter must contain. The only reason the Aron meter has been so successful is that it is so perfectly made. I do not wish to imply that the Aron meter in the future is not going to be perfectly made, but I think that as time goes on and competition becomes keen there will be a great temptation not only to reduce the number of parts in the meter, but also to reduce the workmanship, in order to make them cheaper; and then will come the time when the difficulties with clock meters will come in. I do not say there are not difficulties with motor meters; but, being simpler mechanisms, it seems to me the difficulties are less serious. But the question of what will be *the* meter of the future, if there is going to be a single type—and I think it very probable that there may be only one type, just as we have now one type of gas meter after many types have been tried—is all in the future. One can only say, Try these various meters, and let the best meter win.

Mr. Hammond.

Mr. R. HAMMOND: With regard to Mr. Holden's meter, I am sure that we shall all join with Mr. Evershed in thanking him for his splendid paper. The electric lighting industry, as now constituted, only began to live and breathe when a good meter was invented. But, even now, for the first few months the meter is a very trying thing for the consumer; even if it be true that this meter will start with a current of 2 per cent of its capacity. Various local authorities have been very surprised to find that their meter will not start with one light; but this meter will begin to record with a current of 2 per cent. of its capacity, and that is a great advance. I would like the author of the paper to say if he has plotted out a curve showing the efficiency of the meter throughout its varying loads. I have very often tested meters which were exact at about half-load, and then registered too quickly beyond that point. With Mr. Evershed, I should like, too, to know how the meter behaves over a period of time. I remember once making an arrangement to test the meters of a well-known firm of manufacturers. They came up one day with three meters and put them down before me, and said they wanted to catch the five o'clock train back, and would like to take my certificate with them. I asked them to call that day six months. I have the greatest faith in the time test, and in the test of efficiency under varying loads. There is another test which Mr. Holden perhaps has not thought it worth while to consider. In electricity supply a variation of pressure at the terminals is not unknown, and I would also like to ask Mr. Holden whether he has tested the meter at varying voltages. With the variations which we sometimes get, say on Christmas Eve, or on very foggy days, has that variation an effect upon the truth-speaking qualities of the meter? The meter on the table is in a pleasant atmosphere now, and in a situation where it would work very nicely; but meters are not put in such pleasant surroundings in ordinary application; they are often placed in very damp cellars, and I would like to know whether to any extent the accuracy of the meter is affected by its surroundings.

We have heard nothing about the cost of this meter. Of course it is a purely commercial question, but it is one which may remotely interest us. Somebody has got to pay for it, and it would be very gratifying to me, as one who has occasionally to advise on the purchase of a large

number of meters, to know that so good a meter can be purchased on commercial lines. Finally, it is to be hoped that the upkeep of the meter will not disappoint us. There is a tendency throughout the industry at the present time, although the Act of Parliament allows us to charge a rental upon meters, for consumers to ask us to imitate the gas suppliers and charge them no meter rent. If no meter rent is to be charged, one would like to know—of course Mr. Holden has had no experience to guide him—what are the parts in the meter which will need upkeep, and to what extent the accuracy of the meter is affected before those necessary repairs are effected. I should like to have those points tested for twelve months—I should advise Mr. Holden not to hurry it—before it comes on to the market, in order that he may be able to solve these points. Mr. Hammond.

Mr. H. HIRST: I do not think I can say anything better than what Mr. Evershed has said on the subject of the paper. With regard to the Aron meter, I do not think the quality will deteriorate as quickly as he fears. Mr Hirst.

Mr. A. P. TROTTER: This meter has been under test for some time in my laboratory, but I do not feel at liberty to speak to it, because I do not know anything about its accuracy at present. We have as yet only given it a general running test. I want to make this remark, because other meters share a disadvantage which this one has from a testing point of view, namely, that it is very difficult to get what we call a "counting run" upon it. With the ordinary motor-meter running at moderate speed one can watch and count the revolutions, but in a meter of this kind it makes one revolution and a bit, and in the paper we find revolutions are recorded to the second and third place of decimals. It is very necessary that this meter and others should have a more quickly moving dial. I must congratulate the author on being one of the first at this Institution, and I think I am right in saying the Institution of Civil Engineers also, to introduce a practical example of a calculation of probabilities into a paper. Perhaps the author in his reply will make his description of Fig. 5 a little more clear than it appears in the paper. Mr. Trotter.

Professor W. E. AYRTON: With reference to what Mr. Hammond said about the variation of pressure, the most ingenious meter which Mr. Holden has brought before us this evening resembles the Aron meter, and also the Evershed meter, in being an *energy meter;* that is to say, it *does* take into account variations of pressure at the consumer's terminals, and if the supply company drop that pressure and lower the brightness of the lights, the bill quite rightly goes down. But energy meters have a defect, and this is, that if the supply company—as the Westminster Company have recently been alleged to do in many instances—raise the pressure and break the lamps, then the bill, before the lamps break, goes up, and that obviously is not what a meter ought to bring about. A meter, if it were possible to so make it, ought to fine the supply company when the pressure goes up as well as diminishing the bill when the pressure goes down. Professor Ayrton.

It is very interesting to come across a meter which starts recording with only 2 per cent. of full load, because the earlier meters, as is well

Professor Ayrton.

known, did not record at all until the load was a very much larger percentage than 2. On the other hand, there have been other meters, notably the one brought before this Institution just this time last year, which started with only 1 per cent. of full load, a motor meter. As Mr. Evershed has pointed out, the great superiority of a feeler meter, like that of Mr. Holden's, is the small amount of power it absorbs, so that whether the supply company pays for the energy wasted in the meter, or whether the consumer pays, it is not a very important matter, because the amount of energy consumed in the meter itself, as distinct from the energy which it passes and measures, is very small. On the other hand, all these feeler meters appear to me to possess a very great disadvantage, because they are really intermittent meters; that is to say, they do not give you a continuous record, and they only take into account what is the state of things at certain fixed times. Mr. Evershed has said so much about meters in relation to their law, that I will confine myself to the law in relation to meters. What the law may be concerning the matter to which I am going to refer I know not, therefore I will put my suggestion in the form of a question. I will suppose that Mr. Holden puts up one of the very excellent intermittent meters to measure the energy given to my house or my factory. I suppose, as long as I do not do anything to disturb the supply to other consumers, and of course as long as I do not in any way disturb the meter itself, touch it, or interfere with it in any way, I am within the law. But now, cannot I do this? Cannot I put in my house another clock, my own clock, and use this clock to close a switch? It will close the switch and keep it closed during, say, 55, or even it may be 59, seconds in every minute, and it will then open the circuit during the remaining second. I suppose that is legal, for electricity is supplied to my house, and, of course, to my laboratory for conducting experiments. One of my experiments has to do with an ordinary clock. (Laughter.) During that longish period in every minute, 55 or even 59 seconds, I shall charge accumulators, and during the remaining second I shall not do anything. My bill will be reckoned on the supply taken during that second, and therefore will be nought, but I shall receive a very large amount of electric energy.

Mr. Crawley.

Mr. C. W. S. Crawley: I should like to ask Mr. Holden one thing about his brake. How much of its action is due to hysteresis, and how much to eddy currents? Being in iron, the latter will vary some 0·7 per cent. per degree Cent.; so, unless the effect due to them is small they will introduce a temperature error.

Mr. Campbell.

Mr. Albert Campbell: First, with regard to the action of the earth's magnetic field upon the meter, Mr. Holden very properly alludes to this and shows that at one-twentieth of full load the variation caused is 4 per cent. I think it should be kept in mind, however, that this means a total range of variation of 8 per cent. In the case (which is not at all uncommon) of a meter being used whose range is far above its normal load, *e.g.*, a 30-ampere meter for a house which never takes more than five amperes, a possible variation of 8 per cent. at the smallest loads may be somewhat serious.

Secondly, I should like to ask Mr. Holden if he finds no trouble with

the spark where the shunt-circuit is broken, and also if the sparking does not become more troublesome when alternating currents are used? Mr. Campbell.

I do not think that Mr. Holden has said anything about overloads. Now it is very important that meters should not be damaged by being even considerably overloaded, and some types of meter behave rather badly in this respect. In Mr. Holden's meter one of the moving parts is constantly having its motion suddenly checked; it would be interesting to hear from Mr. Holden how the meter stands the extra jarring caused by repeated overloading.

Mr. C. V. Drysdale: Mr. Holden is certainly to be congratulated on having produced a meter which is different in principle to any other we have yet seen, and which cannot be brought under ordinary rules of classification in meters. His meter also has the great advantage of being an energy meter, and of being suitable for either direct or alternate current circuits, though it would be a matter of interest to know whether the same meter could be placed on either circuit. I venture to think that the matter of universality in any meter is one which is of the greatest possible importance. The meter of the future will surely be one which can be used on any circuit without a radical modification of its parts. As we all know, the cost of the production of any instrument when suitable methods are adopted depends principally upon the number of identical parts that can be turned out, and as the competition grows keener in this direction, not only will the more complex and expensive meters have to be discarded, but also those which are only suitable for a restricted range of work. Mr. Drysdale

As to Mr. Holden's meter, I am inclined to agree with Mr. Evershed that the meter of the future will be a simple motor meter. Any one who looks at the clockwork meters in use at the present time must have the impression that such instruments, however perfectly they may work at first, can only have a limited course to run. They may be necessary at present while other meters are not perfected, but must inevitably go down as simplifications are introduced. I think that even at the present time there are indications of this, and that most engineers are finding the more complex clockwork meters unreliable after considerable use, although they may perform well at first. The advantage of the simple motor meter, when care has been taken to eliminate its frictional and other errors, as has been done by Mr. Evershed, is that it is suitable for any circuit, the only modifications necessary being in the winding of the main coils, and in the resistance in series with the shunt coils for different ranges. It is simple in its construction, and probably if made in large quantities could be turned out more cheaply than most of the other meters. It has also the advantage of being continuous in its action, which is certainly a desideratum, other things being equal.

I should like to mention one point which seems to me to be of some importance in connection with the design of all meters. It is, I think, now generally admitted that the ideal meter for all purposes is an energy meter. The consumer purchases energy from the supply company, not current, and it seems rational that the meter should measure this energy. Professor Ayrton has certainly pointed out one defect of

Mr. Drysdale.

the energy meter, that where the supply company raises its pressure unduly, thus causing breaking down of the lamps, the consumer is debited with the greater amount of energy. On the whole, however, this does not seem to be a serious objection. In the first place, supply companies are to a certain extent restricted in their range of pressure; and if the supply is constantly high by a few volts the consumer has the remedy in using lower efficiency or higher voltage lamps.

An interesting question, however, comes up when we consider the case of the user of alternate-current power. Where power is supplied for running alternate-current motors it is undoubtedly correct to use an energy meter which records the actual energy which the consumer takes from the company. Let us suppose, however, that the consumer uses a motor having a very low power-factor, a point of little importance to him as long as the efficiency is fairly high; the supply company may have to supply an amount of current 30 to 100 per cent. or more in excess of the actual energy current, depending upon the loading of the motor. This current is being supplied through their mains, and has to be generated, transformed, etc., and although the generation of the wattless current does not involve the burning of more coal, yet Mr. Mordey has told us in his recent paper that the generation of wattless current probably costs as much as a fourth of energy current. It does not seem fair, therefore, that the consumer should only be debited in this case with the energy that he is actually drawing from the mains, if the supply company is put to this greater expense, and it would therefore be justifiable that he should be charged a higher rate for energy supplied at low power-factors.

The ordinary energy meter with its main and shunt coils appears to afford a convenient method of automatically adjusting the above question. If the shunt circuit of the wattmeter has no inductive errors it will read correctly on all power-factors; but if a certain amount of self-induction is introduced into the shunt circuit, which makes the instrument easier to construct and gives it greater driving force, it will read too high on lagging loads, and the greater the lag the greater will be the error in its reading, and it would not be at all difficult in any meter to introduce sufficient induction into the circuit by solenoids or magnets, so that the amount registered by the meter should bear an adequate relation to the actual cost of the supply. This would not, of course, in any way affect the reading of the instrument with steady currents so long as the impedance was not so great as to seriously diminish the current in the shunt coil with alternating currents. A considerable phase displacement, however, can be obtained in the shunt coil without greatly affecting the value of the impedance.

Such a meter would have the advantage of being more easy to construct, as mentioned above, and would further offer some inducement to the consumer to instal motors having as high a power-factor as possible.

Mr. Holden has unquestionably worked out his instrument most carefully, and it is most interesting to see how the difficulties have been got over by carefully considering the theory of the instrument.

The President.

The PRESIDENT: I want to take a little credit for having coaxed

Mr. Holden to give us this paper to-night. We have been told of the importance of a time test, and how a meter is affected by its surroundings. Mr. Holden has been affected by his surroundings, and he has had applied to him a very good time test indeed. His experience in meters in America and England has been so great and so long-continued, that probably he may be said to have had longer and better experience of meters than anybody else living at the present time. I will now call upon him for his reply. The President.

Mr. FRANK HOLDEN, in reply: I will deal with Mr. Evershed's remarks first. As to the question of tests over a long time, I may say there have been only a few meters built. The instrument was constructed originally for the fun of it; it worked well, and I am now seeing how it will work commercially. There are fifty being made to see what happens. Mr. Holden.

As to a good many of these questions with regard to the time test, I can only repeat there have not been many instruments made. There is one at the Board of Trade—it has been there about a year, I believe; there is this one here, and I have two others that have been running over six months.

As to meters with clocks being complicated, I have felt more or less as Mr. Evershed has. There is an appearance of complication about clocks, but somehow they seem to work well. We carry them in our pockets, and have little trouble with them.

Difficulties from the contact in making and breaking are quite negligible. The trouble is not with the contact.

With regard to the class of the meter, I can only say I do not know what class it is in; it more resembles the meters on the table than anything else, and I think that I have said as much in the paper.

As to the best meter, the only way to find it out is by trial. When you come to the point, nobody can prophesy how an electric clock is going to work; or, rather, they can prophesy, but it is really guess work. I have found that out.

I would say that I appreciate Mr. Evershed's remarks about the paper having some merit as to giving information. I tried to give all the pertinent facts, and I am glad he, at least, thinks I have succeeded to some extent.

Mr. Hammond raised the question of accuracy. I think that in the table of figures given on page 956 you get an idea of this, and I might say those figures are really a little unfavourable to the meter, at least when it is new. It is a test on that meter before you. That particular meter has a certain amount of looseness in the upper coil, so that the angle—*theta* I believe I have called it—is not really constant, but depends on the load which shifts it somewhat.

Mr. Hammond wanted to know how it is affected by over-loads. I have tested it up to 500 per cent. over-load, and it is still accurate. I would have tested it higher, but the thing spun round so fast that I could not keep count of it.

You can see by the construction of the dynamometer part, that a variation in the voltage really does not affect it at all. It is a wattmeter, as may be seen from the windings.

Mr. Holden.

Mr. Hammond has said that a meter is usually placed in a damp cold cellar, and he does not seem to like to see the meter standing on that table; but I could not very well bring the damp, cold cellar here. As to cost, I do not know how much it will cost. We cannot sell it unless it is going to be cheaper than other meters. These things look after themselves automatically. However, the cost has been estimated by one of the largest meter makers in Europe, and they say it is cheap.

The question of testing, which was raised by Mr. Trotter, is, I think, a very fair criticism, particularly when the cover is on the meter, and I propose putting a circular band on that revolving part, dividing it into one hundred divisions. As to Fig. 5, there are given four curves showing the amount it will read high or low when the springs or damping are varied. The top curve shows the amount it will read high with different loads, for the bulk of the range it will read 5 per cent. high if you make the damping force 5 per cent. too small. The next curve is for "S" decreased 5 per cent., that is, it practically does not affect it at all. Or only 1 per cent. very low down.

Professor Ayrton has devised a way for cheating the meter. I do not think there is much in that, because you have to get your clock and your meter to sychronise, and if you do not, the first thing you know, the meter will be charging you for taking current all the time when you are not doing so.

Professor AYRTON: The meter cannot charge you too much?

Mr. HOLDEN: It might. For instance, take a special case. If you have a load for one second out of the minute, and that second happens to synchronise with the time of closing the contact, it will charge you sixty times too much.

Professor Ayrton raised the objection chiefly to intermittent meters not keeping exact track of the load. I think when you consider the probability of errors coming in a three months run, you must consider there are something like, I forget how many minutes in the time—130,000 or 140,000, I think, and for each one of these minutes there is a positive or negative error equally likely to occur. The errors will cancel out almost to a certainty.

Mr. Crawley has asked as to Foucault currents in the disc. There really cannot be any of any account, as the magnetic induction passes through the disc in such a way. As to the earth's field, Mr. Campbell points out it might read 4 per cent. high or 4 per cent. low. To a certain extent that statement is a guess as to whether it is important or not. I really cannot get hold of any figures to work at accurately or in a definite way. It really depends on how much energy is taken at 5 per cent. of full load. A small amount of energy is taken ordinarily, and I imagine that is the case almost always. Then, as to the sparking on alternating or direct current, there is not very much difference. Of course on alternating sometimes there is no spark at all, and another time you have a spark. The alternating problem is really the harder; it is a harder one for the clock.

The President.

The PRESIDENT: I will now call upon Mr. Gavey to give a demonstration of the Poulsen Telegraphone.

POULSEN'S TELEGRAPHONE.

Mr. J. GAVEY: It will be remembered that a short time ago, in a paper which I had the honour of reading before the Institution on the subject of the Paris Exhibition of 1900, I described briefly what I considered the most interesting of recent electrical inventions, viz.: Poulsen's Telegraphone. At that time I was not able to show the apparatus at work, but the Council have now, through the courtesy of the owners of the patents, found themselves in a position to show it in working order to-night, and I have been requested to give a brief explanation of the system. Mr. Gavey.

The various transformations of energy that take place in the transmission of telephonic speech are well known. It will be borne in mind that the mechanical vibrations of the diaphragm, set in motion by the vocal sounds, either generate or set in motion electric currents in the connecting wires. When a magnetic telephone is used, the vibration of the iron diaphragm, by constantly altering the magnetic field in which the telephone coil lies, gives rise to an undulating series of currents, the exact counterpart of the sound-waves which impinge on the diaphragm. Where a microphone is used the variation of the pressure on the loosely-packed carbon sets up variable resistances in the local circuit of the permanent battery connected with the microphone, and this results in a corresponding variation in the current which traverses the circuit. At the receiving end, when telephonic speech is being exchanged, the exact converse of these operations takes place with the well known results.

It occurred to Mr. Poulsen that, instead of converting the electrical energy directly into articulate speech, he might impress a permanent magnetic record of the electrical waves on a steel band or wire if this were passed rapidly between the poles of the receiving magnet; and this he found in practice he was able to do. Thus, instead of setting a diaphragm in vibration, he gets what may be described as a series of parallel magnets of varying degrees of strength, and with their polar extremities transverse to the wire and laid side by side along its whole length (illustrated on board). Now if the wire on which this magnetic picture has been drawn is again passed in the same direction as before between the poles of the electromagnet, and a receiving telephone is attached to the latter in the place of the transmitting microphone, the magnetic wire, as it is carried past the poles of the electromagnet, practically acts as a generator or dynamo, and variable currents, which are the exact counterpart of the original currents which impressed the magnetism on the band, are generated, and they react on the telephone just as though they had been received from the original microphone in the first instance. It seems almost impossible at first to realise that such a complete and accurate series of magnetic curves can be impressed on a steel wire or band running at a high velocity, but that it can be retained for an indefinite period; but such has been proved to be actually the fact. This magnetism can, however, be wiped out by again running the wire through a permanent magnetic field, either between poles of the electromagnet through which a

Mr. Gavey. permanent current circulates, or between the poles of a permanent magnet itself. This, of course, merely distributes the magnetism uniformly along the band, and thus, when the wire again traverses the poles of the electromagnet as it conveys with it a uniform magnet field, no currents are generated, and no sound is heard in the telephone.

There are two different types of apparatus illustrating the Telegraphone now before the meeting. In the first, the cylinder, on which is wound a long spiral coil of steel wire, can be uniformly rotated by means of a suitable motor. A small electromagnet is mounted on a movable carriage, and it is carried along the spiral coil by the revolution of the latter. At the end of its traverse it is brought back by a quick-motion screw of the spiral to its point of origin, when it is ready to start again, either to reproduce its speech or to wipe out the record.

The second type of telegraphone, which I hope will be the means of making a speech audible to the whole audience, consists of a steel wire or band running at a high velocity over the poles of a series of electromagnets. The first of these is connected to the microphone into which the speech is uttered, and the remainder are connected to separate and individual telephones. Finally the band passes between the poles of a magnet, which wipes out the record. The magnetic impress of the speech from the microphone as it rushes by and reaches each electromagnet, repeats that speech into the corresponding telephone, and finally the record is wiped out, and a clean surface exposed for the reception of fresh impressions.

The President. The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected :—

Associate Members.

William Casson.
John Hutchinson.
Cecil William Kennaway.
Arthur Willmott.

Associates.

Louis H. Bainton.
Brudenell Plummer Bogle.
Reginald Browne.
Harry Beckingham Jenkins.
Harold Alexander McGuffie.
Harry Scholey.
Philip Debell Tuckett.
Edmund Sydney Williams.
Joseph Woolf, junr.

Students.

Albert Josiah Austin.
John Blundell Butler.
Herbert Henry Clare.
Albert George Fox.
George Watson Kidd.
James Milne.
Thomas Alfred Mitchell.
Francis Edmund H. Peel.
Arthur Ferguson Pollock.
Arthur Reginald Walmsley.

MANCHESTER LOCAL SECTION.

Paper read at Meeting of Section, March 12th, 1901.

THE APPLICATION OF STEAM POWER TO THE GENERATION OF ELECTRICAL ENERGY.

By JOHN S. RAWORTH, Member.

The best point of view from which to study an object is not usually the nearest; only few of the beauties of the sea are visible to the man who is up to his neck in it; we, therefore, who work amongst steam engines and dynamos must occasionally, like the painter, step back a few paces in order to obtain a better view of the general effect and tendency of our work.

There is a section of the public, by no means small, that imagines that electricity in itself is a source of power, and that the electric century will soon get along quite well without either steam or coal.

At present there is no prospect of any such development; on the contrary, electricity has made steam power applicable to many purposes for which in the past it was useless, and to that extent it has increased the demand for steam engines; moreover, since it has enabled us to distribute power wholesale or retail as required from a common source, its tendency is to increase the size of the individual units to an extent beyond the limits of our comprehension.

The first effect of the invention of the dynamo was to raise up a demand for small steam engines, which continued active during several years, because the early efforts of electricians to build dynamos of large sizes were not rewarded with success. Even so late as the year 1893 the City of London Electric Lighting Co. could not obtain in England or America machines of 500 k.w. output that were entirely satisfactory; though from that date forward progress has been very rapid, so that we now find in New York the power-station of the New York Elevated Railway Company contains 11 units each of 7,000 H.P.

The history of steam engine improvement in this country during the seven years is very remarkable. The established builders of large engines in Lancashire and

Yorkshire have stood aside and have left comparative outsiders to wrestle with the problem; Willans, Belliss, Brush, Browett, Ferranti and Maclaren have each on independent lines endeavoured to find an answer to the question, "How shall we drive a dynamo?" A few years ago the big engine builders appeared to think the electric engine beneath their notice, but now Electricity demands engines bigger and better than Bolton can build, with this result that Allis and Sulzer Bros. have both succeeded in pulling plums out of the British pie.

I do not affirm that either Allis or Sulzer engines are better than our Bolton engines, but their buyers have been made to believe them to be better.

I have no experience of Continental engines in work, but of American engines I have had more than enough. The conclusion I have come to is that on the average they are strong plain engines, with good juvenile appetites and a rather abnormal tendency to develop internal complications attended sometimes by external eruptions.

Some electrical engineers seem to think that it is only necessary to order a foreign-built engine to escape from all their woes. But they are wrong; there is no escape for an engineer—he must climb over his difficulties, he cannot dodge them.

It is a curious and remarkable fact that whilst in different countries dynamo design has shown a strongly marked tendency towards uniformity, steam engine designs have been and still are divergent. In England we have the three-crank high-speed vertical as the leading type. In America the side by side compound horizontal or vertical slow-speed engine predominates, whilst in Switzerland and Germany there is a marked tendency to develop the compound tandem engine on one crank.

The English engine is the cheapest, and gives theoretically the best turning effort.

The Swiss engine is the most economical in steam consumption, and the most wasteful in land and buildings.

The history of the development of the English pattern is very interesting. The early attempts at "Electrical Undertaking," that is to say the distribution of electrical energy for all purposes within the boundaries of a parish or municipality, were made in London, and as you know

the first generating stations were constructed in basements beneath and amidst valuable property, inhabited by nervous and sometimes impecunious people.

There were few good engines suitable for the purpose, and the best of the few was the Willans, but its speed was high, and its moving parts heavy, hence came vibration, followed by claims, writs, lawsuits, and compensation.

In those days the Willans engine was a two-crank engine, equivalent to a single-crank double-acting, and it would probably have remained in that stage of its development if the vibration trouble had not become acute; but in 1895, Captain Sankey and Mr. Mark Robinson produced their paper on a method of preventing vibration in steamships, in which they showed that a three-crank engine provided a good practical solution of the vibration problem, and gave a more equal turning moment than the two-crank arrangement: this latter consideration was, however, of trival importance, because no trouble had arisen with the earlier engines in this respect. An experiment carried out by Mr. Mordey, at Thames Ditton, in 1887, showed that alternators direct-coupled to Willans two-crank engines, worked perfectly in parallel. The three-crank engine therefore exists by virtue of its excellent internal balance—this is its good point; its bad point is its lack of economy, due to three causes—first, leakage length of piston ring 73 per cent. more than that of single-crank engine of same stroke and revolution, 73 per cent. more area of cylinder walls, and the almost insuperable difficulty of applying automatic expansion.

The question will rise to your lips, why is it difficult to apply automatic expansion when Maclaren does it quite easily. The answer is that the Maclaren engine is not one of the class described—it has three cranks, but it is not balanced either in turning moment or inertia effect, it is simply a triple expansive marine engine with three cylinders, three cranks, and an expansion governor; whereas the modern three-crank engine has a complete compound or triple tandem engine on each crank, consequently the turning moment and the balance is nearly perfect at all loads. With this engine we have either six or nine cylinders, and internal packing rings too numerous to mention.

This engine has some excellent qualities. It is suitable

for use in positions where vibration cannot be permitted, and it enables the designer to use a shorter stroke and higher speed of revolution than with any other of the existing designs of reciprocating engines. On the other hand, it is less economical in steam than the same build of engine on one or two cranks, and it passes the wit of all engineers save Captain Sankey to make its expansion automatic. You are well aware that the Willans engine has had automatic expansion applied to it in two-crank and three-crank patterns, but we hear no more of it; we may, therefore, conclude that except as a triumph of human ingenuity this elaborate and most artistic device has sunk into the region of things that are not.

I have referred to the excellently equal turning moment of the "three-crank engine"; this is no myth, in the Willans and Belliss engines and in all engines of similar design it is a substantial fact, and if it had fallen to the lot of those engines to have been called upon to work at 70 to 120 revolutions per minute it would have been an *important* fact; but their lot has fallen in pleasanter places, their speed of revolution is usually between 200 and 500 per minute, where all questions of turning moment vanish and it becomes impossible to distinguish between the results of a single-crank and a three-crank engine.

I have no experience with three-crank engines, but I have no reason to doubt that their results as judged by steady current are nearly independent of speed; but with single-and two-crank engines, the result of my varied experience is that there is no happiness under 200 revolutions per minute with any size of engine, and above that speed all difficulties vanish.

At the Wandsworth station of the County of London Company, there are six 300 H.P. engines driving Mordey Alternators in parallel. The result is perfect, although all the engines have single cranks. Moreover there is no apparent difference when the exhaust is taken to the condenser or the atmosphere, though the effect of changing from one to the other is to destroy the balance between the up stroke and the down stroke. The speed is 213.

I submit that this example settles the question of the suitability of single cranks. There is a very general belief that with two cranks at right angles the turning effort is

more equal than with a single crank. At slow speeds the popular belief is justified by experience, but at high speeds there is not much difference between them, so little indeed that in a two-crank *vertical* engine it is better to set the cranks opposite than at right angles.

Mr. Edgar Ingram, at Bournemouth, received a two-crank Universal engine from the Brush Company, in which the cranks were set at right angles, but on trial the parallel running was found to be imperfect. He then coupled the engines at 180°, with this result that the parallel running is now quite satisfactory.

In a horizontal engine the improvement would not be so evident, the insistent weight of the moving parts on the cranks being eliminated.

In this connection it is worthy of notice that builders of long-stroke horizontal engines very rarely balance their cranks. The effect of the weight of the crank on the turning moment of the engine is small, but it is definite, and it can be balanced with ease and certainty; it is therefore desirable that it should be done in all cases. In engines with two opposite or three equally spaced cranks, the cranks balance each other.

Now that interurban generating stations have become nearly obsolete, the vibration question has sunk into comparative insignificance, and we may well ask ourselves the question whether it is desirable to go on developing the three-crank engine with fixed expansion and six or nine cylinders, when better results can be obtained with more simple and less expensive designs.

In considering this phase of the subject, there is, as usual, a compromise, and it is worthy of note that it has received very little attention.

At an early stage I mentioned that a three-crank cylinder triple engine on three cranks is not a good high-speed arrangement, on account of the large size of the low-pressure piston and the unequal distribution of effort at varying loads.

A three-cylinder compound engine on three cranks possesses these disadvantages in a much smaller degree. The two low-pressure cylinders are only slightly larger than the high pressure, the weights of the lines of parts can easily be made equal, the effort of each cylinder at varying

loads is much less diverse than in the triple, and it is a simple process to apply automatic expansion.

It is probable that an engine on these lines has been built, but I have never seen one except in marine practice.[1]

It is very rarely that a triple engine possesses a practical advantage over a compound in electrical work, and this already rare advantage will disappear with the general adoption of super-heating.

Mr. Wilhelm Schmidt tells me that he can obtain the best results with a compound engine, and hot steam. Having these facts in view, I shall be very much surprised if the three-crank three-cylinder compound does not become a favourite for large units of from two to five thousand horse power. English engineers and even Oldham aldermen have at last got over their objection to enclosed engines.

They reluctantly recognise the fact that at 300 revolutions per minute the connecting-rod ceases to be a thing of beauty, and that oil is better inside the engine than all over the floor.

It has taken twenty years to get to this point, but having arrived we shall never go back. The Swiss engines are very impressive from the Bolton point of view, the cylinders alone at the Zurich power-station are 24 feet long. I think if I had a cotton-mill and a large family of girls I would have one of those engines just for a luxury; it would be quite as seductive as a picture gallery and less expensive.

Lancashire does not recognise the high-speed enclosed engine; it has not yet been "introduced," but it will be soon—the 2,500 H.P. engines of Browett & Lindley, at Salford, will leave their card.

Let me try to clear this question:—

High speed of revolution necessitates enclosure.

High speed increases economy. (See Willans' papers, Civil Engineers, 1888—1893.)

High speed improves turning effort.

High speed reduces prime cost of engine, land, and buildings.

High speed does not involve abnormal wear. (See Mark Robinson's paper, Electrical Engineers, 1897.)

The designing of enclosed engines is an art: it does not

[1] I have since learned that Messrs. Musgrave have built an engine on these lines for the Glasgow Tramways.

consist in simply casing an engine with cast-iron. The engine, though enclosed, must be accessible, and provision must be made for the continuous lubrication of every joint.

Any one who has attempted to design an enclosed engine will understand the difficulties, of which there are many working examples.

The application of indicating gear to high-speed engines has only been partly faced ; indeed it is nearly impossible to take a satisfactory set of diagrams from some of the six and nine cylinder three-crank engines.

There are two principal methods of lubrication, which may generally be divided into the Willans and the Belliss systems.

Willans depends on the splash.

Belliss pumps the oil through the bearings.

Both give good results, but Belliss obtains much higher efficiency at light load than Willans—this may be partly due to flush of oil, but it must be remembered that the Willans engine has no such thing as light load on the bearings, the moving parts are abnormally heavy, and there is no cushion on the down stroke, consequently the bearing surfaces are subject to severe pressure, even when there is no external load ; it is quite possible, therefore, that the coefficient of friction may be nearly, if not quite, the same in both engines. I have tried both systems, and have found no difference between them ; although I get 15 lbs. pressure in the oil pipe, I do not believe that there is any pressure between the bearing surface, except the pressure that comes through the connecting-rod ; nevertheless a constant flow of oil through the bearings is good, it washes out the dirt.

The question of automatic expansion is constantly before us, and although it is bound to conquer in the end, the victory has been very much delayed by the advent of the three-crank engine.

Captain Sankey showed, in his paper, read before the Institution of Mechanical Engineers in 1895, that automatic expansion is always more economical than throttling except at light loads.

At light loads throttling is superior in economy, therefore he devised his ingenious arrangement for expanding down to 14 lbs. mean pressure and then throttling. The moral of this is that trip gear for twenty years has been

obtaining our admiration on false pretences—it is pretty, but not economical. The simple shaft governor, despised because it shows throttled diagrams at light loads, is now discovered to be theoretically and practically perfect.

I have only one word more to say, and that is that we now hear no more about special engines for traction purposes; the great fly-wheel craze has burnt itself out; English engines built for electric lighting purposes are driving tramcars most successfully; the appalling descriptions of "destructive stresses" invented to frighten English buyers into purchasing American engines are to be found lying in the Journals of the Institution.

There let them lie.

CALCUTTA LOCAL SECTION.

INAUGURAL ADDRESS OF THE CHAIRMAN,

Delivered March 15th, 1901,

By F. G. MACLEAN, Member.

We are met to-night to inaugurate a Local Section of the Institution of Electrical Engineers: an Institution which started life in 1871 in London as the Society of Telegraph Engineers and was composed of a few members, nearly all of whom were connected with telegraphy. As time went on and the applications of Electricity were extended to other purposes than Telegraphy, it was found advisable to change the designation of the Society to "The Society of Telegraph Engineers and Electricians," under which title it was incorporated in 1883. The subsequent rapid development in electrical enterprise soon rendered a further change of name desirable, and in 1889 the Society became "The Institution of Electrical Engineers." Starting as a small Society with but few members, the Institution on the 30th of June last numbered 3,661.

To meet still better the growing needs of the profession, it was decided to permit the formation, in different parts of the Empire, of Local Sections of the parent Institution, and, in response to our petition, the Council in London have now constituted a Calcutta Section, which will for the present embrace all India till such time as other cities may form sections of their own.

On this occasion, gentlemen, it may be of interest to make a few remarks on the history of the progress of Electricity in India. If my remarks appear to be little more than a *résumé* of the work of the department I have the honour to direct, I would ask you to remember that until the last few years Electrical work in India has been practically confined to Telegraphs.

There are two points of interest to which I should like to call your attention. One is that this year, in which we are inaugurating this branch of the Institution, is the first of a new century. The second point is that this year marks the completion of fifty years since Dr., afterwards Sir

William, O'Shaughnessy first carried to a practical conclusion his idea of an Electric Telegraph in India. In fact it is the Jubilee Year of the Telegraph, which in India as in all other countries has been the Pioneer of Electrical Engineering. The history, therefore, of Electricity in India is confined to the latter half of the past century, and during this fifty years our record of progress, I regret to say, can scarcely be favourably compared with that of many other countries. This, however, will be no matter of surprise to those acquainted with the conditions of the country we live in.

As you are all doubtless aware, the first practical telegraph line was opened in England in 1837. Two years later, in 1839, Dr. O'Shaughnessy, of the Medical College, Calcutta, erected an experimental line in the Botanical Gardens. It was 22 miles long, erected on parallel rows of bamboos and was composed of iron wire No. 14 B.W.G., which was well tarred. Several experiments were made with this wire, and, as a final result, Dr. O'Shaughnessy proposed to signal by means of shocks in the following ingenious though impracticable way. At each end was placed a clock, the two being kept in synchronism, and over the dial of which moved a seconds hand pointing to different letters of the alphabet. When the pointer arrived at the required letter, the sender would transmit an electrical shock by means of a small induction coil, and the receiver seeing the position of his pointer would note the letter required. We hear nothing more of this system of shocks, and doubtless it failed, either from difficulty in synchronising the clocks or from the inefficiency of the human receiver. Dr. O'Shaughnessy, however, was thoroughly convinced of the practicability of the electric telegraph from these experiments, but he found it more difficult to convince the authorities, and the next ten years appear to have been spent in endless experiments and reports. His indomitable patience is a splendid example for all time to impatient pioneers in science. In 1851 the first practical telegraph line was built from Calcutta to Diamond Harbour, and in the following year it was extended to Kedgeri, making, with some short additional sections, a total length of 82 miles. This line was made of iron rod $\frac{3}{8}$-in. diameter. On the overhead sections it was supported on bamboos 200 to the mile; on the under-

ground sections it was first wrapped in two layers of Madras cloth saturated with pitch and tar and then laid within a row of roofing tiles filled with a mixture of sand and rosin. This line was remarkable for its strength. A terrific hurricane swept over Bengal in October, 1859, levelling giant trees and houses of stone and mortar. Two steamers, the "Powerful" and "Precursor," were blown on land. Yet the line stood uninjured, the bamboos bending to the storm. I would mention as a particularly interesting fact that some of the underground portion was dug up so recently as 1888, and not only the iron but even the Madras cloth was found in perfect state of preservation.

Before making further remarks, it is with the greatest pleasure that I notice among our guests to-night Dr. O'Shaughnessy's faithful assistant from the earliest days of the department. I allude to Rai Seeb Chunder Nandi Bahadur, late an Assistant Superintendent of Telegraphs. If, gentlemen, he could be induced to speak, I am sure he is in a position to give an account of the many difficulties he was enabled to overcome by his ingenious devices and perseverance, and I am sure that he will be prepared to give the history of most of the relics of the past which we have here to-night.

Dr. O'Shaughnessy was keenly apprehensive of the effect of lightning on his signallers, and to protect them the line was always taken underground before entering an office, for, in his opinion, it constituted "the best of all protections from the appalling dangers of the thunderstorms." He also discovered independently the efficacy of the earth as a return circuit, which had, however, been previously discovered by Steinheils in Europe. The problem of crossing rivers was one of the first that pressed for solution in India. Dr. O'Shaughnessy tried signalling through a bare wire laid in the bed of the river. This succeeded to a certain extent, but was abandoned on account of the delicacy of the receiving apparatus required. In May, 1851, *i.e.* fifty years ago, he succeeded in signalling across a river over 5,000 feet in breadth without any conductor. It would seem that signals could not be maintained and the battery required was enormous, so this system was also abandoned; however, it remains as a remarkable achievement in wireless telegraphy. Nothing

practicable was done till gutta-percha covered wire was imported from England, and then, after many trials, the system adopted was to secure this insulated wire in the angles of a strong chain cable.

The success of this first pioneer line along the River Hughli quickly convinced the authorities of the utility of the telegraph, and in October, 1853, was commenced the construction of a network of telegraph lines all over India. These lines were first erected without any attempt at insulation, and we read in a report of Dr. O'Shaughnessy, "It has been ascertained that electrical insulation is of very small necessity or importance even when many lines are on the same posts." He, however, subsequently changed his mind, and invented an insulator. Since this time the course of improvement has been the substitution of iron for wooden supports, the improvement in pattern of insulators, the gradual reduction in the weight of the wire used, and finally the use of copper instead of iron wires.

The first receiving instruments used were small horizontal galvanoscopes of very simple and cheap design. They were very sensitive, but difficult to read. In 1857, Morse instruments began to be introduced. Then came the mutiny, when the enormous utility of the electric telegraph was clearly proved.

After the mutiny, progress was rapid, and by the 31st of March, 1858, there were 10,000 miles of line in operation or under construction.

In the same year the first cable was laid between India and Ceylon, a distance of twenty-five miles. It was laid from a native sailing vessel during bad weather: a truly remarkable feat at that time, when to lay a cable across the Straits of Dover it was considered necessary to employ a squadron of steamers and costly machinery. At this time also was introduced the system of receiving by sound, instead of by sight, from a galvanoscope, by which twofold greater accuracy was reported to have been obtained.

In 1864, through communication with Burmah was established after an unsuccessful attempt four years earlier.

In 1865, through communication was first established to England by the Turkish route, while the route *viâ* Persia was opened in January, 1870, and *viâ* Suez and Aden in March, 1870.

In 1874, Duplex Telegraphy was introduced. Duplex telegraphy is the simultaneous transmission of two messages in opposite directions on the same wire. This system with good lines is found comparatively easy to work, and now all the main lines are worked duplex.

In 1885, Quadruplex Telegraphy, or the simultaneous transmission of four messages, two in each direction, on the same wire was introduced. It has been found that while this system gives no trouble on iron wire lines up to about four hundred miles in length, beyond this limit much attention is necessary to get good work and the lines also must be in perfect working condition.

More recently accumulators have been introduced to replace primary batteries wherever facilities for charging exist, and the Wheatstone automatic system of telegraphy is now used on some of the main circuits, and messages are sent by this means for long distances such as Bombay or Madras to Rangoon.

As regards Hertzian telegraphy, of which we have heard so much of late, beyond laboratory experiments, no practical system has been installed in this country, but many of us here present may have had the privilege of witnessing the delightfully clear demonstration of wireless telegraphy made two or three years ago in the town by the Rev. Father Lafont. It may be wondered why the Telegraph Department has not taken advantage of the Marconi System, which we all know has proved to be a practical success in connection with marine communication, if not in certain cases over land. The answer is that there are many reasons why this is so, the principal and most weighty among them being financial. I hope, however, before long that we shall be in a position to establish our own system experimentally between Sauger Island and the Sandheads. But it should be remembered that wherever the ordinary telegraph can be used, it is at present by far the most efficient and reliable.

To turn to other applications of electricity, the first record I can find of an electric light installation in India was about 1879, when Mr. Louis Schwendler, of the Telegraph Department, erected an installation to light a goods-shed in Howrah station yard. On this occasion he had no *ammeter*, so he constructed a big tangent galvano-

meter, the coil of which was a single term of stout copper wire six feet in diameter. He also suggested the feasibility of using a dynamo to work telegraph circuits direct, an idea adopted many years afterwards in America.

Various isolated installations sprang up from time to time in different parts of the country, but the first application of modern electrical engineering on any large scale was the electric tramway in Madras. This tramway started in 1894 on the underground conduit system. Unfortunately there were times when the tropical rains of Madras completely flooded the roads in parts, including the conduit, and the whole system was brought to a standstill.

This threw discredit on the conduit system, and a change was made to the overhead trolley system, which has met with success, and the system has been greatly extended I believe. The next application of importance was the Darjeeling electric lighting installation, which is the pioneer of high-tension transmission in this country. It is also the pioneer of Municipal enterprise in the field of electrical engineering. The power is derived from water collected from two hill streams.

In the last year of the century the Calcutta Electric Supply Corporation commenced operations; an undertaking that promises in the near future to be of no mean magnitude. And we are shortly to have a System of Electric Tramways in this town.

Now, gentlemen, while we must sorrowfully admit that this record of achievements in the electrical field is but small, I am glad to think that very shortly we shall not have to reproach ourselves with want of enterprise, for I see unmistakable signs that India is now thoroughly awake to the great advantages of electrical power, and that efforts, and I have no doubt very successful efforts, will be made to bridle and use the enormous natural forces which lie at our disposal. Hardly a week passes without some scheme for the use of electrical power coming to my notice: some schemes hitherto considered chimerical, but now brought forward in a practical form, others new but bearing the stamp of practicability; some small but none the less useful, others of magnitude and promising their promoters financial success. These schemes, I feel fairly confident, are only the forerunners of other proposals, of the intention

of some of which we do not even dream ; but all, whether large or small, offer openings to Electrical Engineering, a profession which, I foresee, will be largely extended in this country before long. The largest and the most important of all the schemes at present proposed is that for the transmission of power from the Cauvery Falls to the Kolar Gold Field, a record distance of about 100 miles, the financial success of which is already practically assured.

Here in Bengal, though intersected with waterways, the conformation of the country offers no such facilities for the conversion of water-power into electricity, but we have enormous advantages in cheap coal almost at our doors, which almost compensates for the want of the more favourable conditions of other localities; and when confidence in the efficiency and convenience of electrical machinery over that of steam for workshops has been once established among the public, as it doubtless has among those whom I have the honour to address, we may expect great changes.

Gentlemen, it would be impossible for any of us here to-night, however vivid his imagination, to fully realise what lies before India in the field of electrical enterprise. I think, however, I may safely say that when the advance of science may again necessitate remodelling our Institution, if not replacing it as too antiquated and behind the times: when my successor, so to speak, addresses his audience and, as I have done to-night, recapitulates the early dates of electrical engineering in India, he will, I anticipate, neglect our little efforts of the past fifty years and take his starting-point from the commencement of the twentieth century, and with it the establishment of this Local Section, which we are all present to inaugurate to-night, and to which, I feel sure, you will join with me in wishing every success.

BIRMINGHAM LOCAL SECTION.

Paper read at Meeting of Section, March 27th, 1901.

POLYPHASE EQUIPMENT OF FACTORIES.

By W. WYLD, Associate Member.

Before proceeding to the subject which we are to discuss this evening, I wish to express my thanks to the Chairman and Members of the Committee for the honour they have done me in asking me to read the first paper after our Chairman's inaugural address to this local section of the Institution.

I had a great amount of diffidence in accepting the invitation, for I felt that this honour should have been for some older member of the profession who had been longer associated with this locality, for I am a comparative stranger here.

It was urged, however, that the work upon which I have recently been engaged was a subject which would bring forth a good discussion, and it is therefore rather a subject for discussion which I wish to bring before you than a paper in the ordinary meaning.

Considering the number of the large power schemes which are now about to be started throughout this country, and seeing that one is to be right in our midst in this district, it is a very opportune time, I think, for a discussionto be held on the system upon which most of these schemes are to be worked, with particular reference to its applicability to the driving of factories, as I think it is from this source that the promoters of these schemes hope to derive a great proportion of their revenue, and, on the other hand, by which the public is supposed to be benefited.

Most of these large power schemes are to be on the polyphase system for the generation and transmission of the electrical energy, but whether it is to be distributed from

the sub-stations as continuous- or alternating-current I am not at all sure; but I expect that this matter will very much depend upon the nature of the demand—*i.e.*, whether the consumers will have an alternating-current supply or not; but if the current can be distributed as polyphase alternating-current, the cost of converting it into continuous-current will be saved and the cost of distribution thus diminished, and the consumer supplied at a cheaper rate per unit.

We are all fully aware of the inefficiencies of the old—the present, in too many instances—methods of driving factory machinery, whereby at least 40 to 50 per cent. of the power is lost in transmission, and probably 10 to 15 times more fuel consumed than necessary. We also all fully recognise the many and great advantages of electric driving, so that there is no necessity to here eulogise them. There are, however, great differences of opinion as to the best methods of obtaining the best results of electric driving in factories. I do not mean to enter into the pros and cons of the different systems of applying motors, &c.—*i.e.*, by either single-motor driving or group-driving, but I refer to the differences of opinion which exist upon the system of current to be used, viz., continuous or alternating.

The continuous-current system has been the most commonly used until recently, particularly in this country, and is therefore the better known. For this reason I will not take up your time by describing it, as it is familiar to all of us; but as the alternating-current system may not be so familiar, and as it is probable that it will be much more used in the near future, I purpose giving a closer description of it.

The alternating-current system may be divided into single-phase and polyphase systems. The single-phase system, however, is not particularly adapted for motor driving, although it is perfectly practicable; the difficulty with single-phase motors being to get them to start on a load. There are, however, in this country about 80 towns supplied with single-phase alternating-current, and in most of these towns there is some motor-load.

Polyphase System.—Any arrangement of conductors carrying two or more single-phase alternating-currents

definitely related to one another in point of time may be called a polyphase system. Although this system has really only come into use to any extent in this country within the last year or two, it is by no means new.

It dates as far back as the year 1879, when Walter Baily showed, in a paper read before the Physical Society of London, how Arago's rotation could be produced by a number of fixed electro-magnets acting upon a copper disc. This paper is published in the *Philosophical Magazine* of October, 1879, which gives diagrams illustrating this principle of the invention and arrangement of apparatus. The latter consisted of a copper disc suspended in the centre on a needle-point, so as to be able to revolve. Under the disc four electro-magnets were placed, with their vertical axes equidistant from the centre and their poles close to the under-surface of the disc. It is interesting to note that these magnets had laminated cores. The exciting currents were supplied by two batteries, and a commutator was placed to alternately reverse the polarity of the field-magnets. Baily says: "The experiment with four electro-magnets may be readily performed by means of a commutator which will reverse the current several times per second," so he evidently recognised that reversals rapidly succeeding each other would give an increased effect.

We have here all the important features of the modern 2-phase motor embodied in an apparatus invented twenty-two years ago.

The next important step in the development of the induction motor was made by Professor Galilio Ferraris, who constructed several two-phase motors in 1885, which were on view at the headquarters of the American Institution of Electrical Engineers at the Chicago Exhibition. The description of these motors was only published in March, 1888; but before then two other patents for motors of this kind were taken out, one by the Helios Co., of Cologne, in May, 1887, and the other by Borel and Paccaud, in February, 1888. Then, three months later, we have Tesla's very complete specification for power transmission by 2-phase alternating-currents, and after that come many others. The production of a rotary field in the motor was explained by Tesla to be produced by employing two

alternating-currents of equal frequency, but having a phase-difference of 90°.

If we build a Ferraris motor with three instead of two pairs of magnets, and energise them by three alternating-currents with 120° phase difference between any two, we shall obtain a rotary field, and so on for any larger number of phases. There is, however, no advantage in employing more than 3 phases, whilst the multiplication of circuits constitutes an undesirable complication, so that for practical work the choice is limited to either 2 or 3 phases.

In the 2-phase system the two E.M.F.'s and currents are 90°, or one-fourth of a cycle apart, hence the relations of the currents to each other are such that the maximum of one occurs when the value of the other is zero. The windings of a polyphase machine may be continued in a number of ways, each affecting the relation of the electromotive forces of the outside conductors.

The winding of most commercial 2-phase machines are interlinked. The current in one phase is 90° apart from, or in quadrature with, the other.

With a 2-phase system either 4 or 3 wires may be used. A 4-wire system consists of two separate circuits, deriving their currents from two independent armature windings in quadrature with each other, or from a continuous armature winding tapped at four equidistant points. These two single circuits must be balanced as nearly as possible, and for this purpose the four line wires must be carried throughout the system.

By joining any two of the four conductors in the 4-wire system, a common return is made for the two circuits. This arrangement is known as the 2-phase 3-wire system.

It may here be remarked that a 2-phase system with four wires is on a par with a single-phase 2-line system; while with a 3-wire 2-phase system it is more, so far as the economy of copper is concerned.

In the 3-phase system the three E.M.F.'s and currents are 120° apart, and the impulses follow each other at 60°.

Each one of the conductors successively serves as a

return for the other two, the algebraic sum of the currents in the system being zero.

The windings of 3-phase generators are usually connected up in one of two ways—either "star" or "mesh." In the former the coils of the armature are joined to a common junction, from which they branch starwise each to its own line.

The pressure between the ends of any two of the generator coils in a 3-phase "star" system is $\sqrt{3}\,(=1{\cdot}732)$ times that between the common junction and the terminals of the coils.

In the "mesh" connection the coils are connected in series, and the line wires joined to points between the coils, forming a closed triangle without any common centre.

An advantage for factory distribution, when transformers are not required, is to be found in the "star" winding, as by its adoption a higher voltage can be used for the motors and a lower one for the lighting, which is a great advantage where incandescent lamps are used.

For instance, at the Patent Shaft & Axletree Company's power plant, the generators are "star" connected, the voltage between the 3 phases which is used for the motors being 350, whilst that from the star connection or common junction is 200, which is quite practicable for lighting circuits.

With the 3-phase system as with the 2-phase, 3 or 4 conductors may be used, but in this case the fourth or neutral wire which is used when the generators are "star" connected, is only used for carrying the out-of-balance current, and need not be larger than about half the size of the other conductors, and when the generators are connected up in "mesh" fashion, 3-line wires are used and then the amount of copper used is about three-quarters that required for a single-phase 2-wire distribution.

In addition to the economy of copper in distribution there are other advantages possessed by the 3-phase system which will be considered in the next paragraph on motors.

Polyphase motors are of two types—the Synchronous and the Asynchronous.

The synchronous motor is very similar to a generator in its construction. It is not adapted for use where a large starting torque or frequent starting on the load is necessary. It does not admit of independent speed regulation, and it has also the disadvantage of requiring certain station appliances, as with a generator, including some source of exciting current, which is usually obtained from some source other than the motor. From these reasons, then, it will be seen that the synchronous motor is not adapted for factory driving.

Asynchronous motors, on the other hand, are well adapted for factory driving. Their simple and substantial construction is one of their chief advantages, resulting in a minimum of cost of maintenance and attendance.

An asynchronous motor consists essentially of two parts, the stationary and the revolving part. In most modern motors the stationary part, or "stator," contains the coils through which the high-pressure current passes from the line. The polyphase currents flowing through these coils produce a rotating magnetic field, this field acts upon the revolving part, or "rotor," and induces in it currents which magnetise it, so that the rotor takes the part of magnet, but is only excited by the induced currents from the surrounding stator, hence these motors are often called "induction" motors.

The principles of operation of the induction motor are thus seen to combine both those of a motor and of a transformer, the "stator" being considered as the primary and the "rotor" the secondary.

When running without load the speed of the rotor is very nearly that of the rotating field produced in the stator, or nearly synchronous, and then there is a very small current induced in the secondary.

The magnetic pull of this current on the field produces a feeble torque, and then the current taken from the line into the stator is only the magnetising current required to overcome the mechanical and magnetic friction of the motor. When running under load, the speed of the rotor falls by a small percentage, and the E.M.F. and the induced currents in the rotor increase with the difference in speeds, and a powerful torque is produced by the pull of this increased current in the rotor.

The difference of the speed of the rotor and that of the revolving field in the stator is known as the "slip," and this is proportional to a certain extent to the resistance of the rotor.

To insure high efficiency and good regulation the windings of the rotor or secondary of the induction motor should have a low resistance.

It will be seen, then, that the greater the load put on an induction motor (up to a certain extent) the greater the slip will be, in order that, at constant voltage of supply, the motor will have a correspondingly greater turning effort.

Absolute synchronous speed is never obtained in an induction motor, for, as has already been shown, there is, even on no load, a certain amount of "slip" required to furnish the current necessary to overcome the light load losses. The fall of speed, from that at light load to that at normal rated load, will vary from 1·5 per cent. in motors of 100 H.P. to 3 or 4 per cent. in smaller motors.

It is sometimes said against the induction motor that it is inflexible in respect to the regulation of speed, but there are several methods of obtaining a variation of speed in an induction motor.

The three most usually adopted methods are :—

1st. The inserting of a resistance in the rotor circuit which may be varied by short successive steps.

2nd. By changing the impressed voltage of the stator.

3rd. By changing the number of poles of the stator.

The first one is the most commonly used, in factory driving, particularly in Europe, on such motors as are used on cranes or printing machinery, &c.

The range of speed demanded of such motors does not allow of the usual small starting resistances being used, which in some makes of motors, particularly American, is placed within the spider of the rotor.

An external rheostat is therefore required of sufficient size to carry the comparatively large though low-pressure current of the rotor. This external resistance or controller necessitates the use of three collecting rings for electrically connecting it with the rotor.

It has already been mentioned that the current taken by the stator, as well as the torque, of an induction motor

depend upon the ratio of the "slip" of the rotor to its resistance.

Therefore, by altering the rotor resistance the speed of the motor may be altered, and the torque and the stator current kept the same.

The second or potential variation method is effected by introducing an external resistance and impedance between the supply terminals and the stator.

By having a sufficient number of tappings on the impedance coils, a graduated variation of the impressed voltage is obtained and a corresponding variation in speed.

It is found, however, in practice that the motor thus controlled has a lower efficiency at full speed than a motor built for rheostatic control. A motor with rheostatic control has the same power-factor at all speeds, whilst one with potential control has a lower power-factor and efficiency at all but full speed.

The third method, changing the number of poles, is effected by winding the stator so that by the movement of a switch the number of poles is changed. Where, however, a great variety of speeds is required, this method is complicated. It also has the disadvantage of the motor only being able to run at full, one-half, and one-quarter speed. This class of variable speed motor is the most efficient at half and quarter speeds.

Of these three methods of controlling the speed the potential one is inferior to the rheostatic one, inasmuch as it is not so efficient, and the changing of number of poles is limited in its range. The worst feature of the best one, the rheostatic method, is that it necessitates collecting rings on the motor, but it must be borne in mind that these collecting rings carry a very low potential current, and my experience of them has been that they give no trouble whatever, and I have several running on cranes of from 5 to 20 tons, some of which are run under very severe and trying conditions.

Let us now consider the relative advantages of the polyphase motor over its rivals. The single-phase motor, though an induction motor, has the disadvantage of being unable to start on a load, as well as being invariable with respect to speed; in other respects it is similar to the polyphase motor.

Coming now to the continuous-current motor, we see the main difference is that the current supplied to a polyphase motor at the full pressure of the mains simply passes through the "stator" windings, which are quite enclosed, and without having to traverse any exposed parts such as commutators or brushes, and as these windings are stationary there is no danger of mechanical injury, and the insulation can be made very secure and so enabled to stand a higher pressure than would be permissible with a continuous-current motor.

This is the most important point in favour of the induction motor.

The revolving part, or "rotor," of the polyphase motor is always of low voltage, requiring very little insulation, and can thus be very much more strongly and mechanically built than a continuous-current motor with its revolving armature, through which has to pass the full pressure current, and if this is of high voltage the winding of the armature has to be of fine wire and expensively insulated, and which is thus much more liable to burn out than the rotor of a polyphase motor. The continuous-current motor requires a commutator to commute the continuous current into an alternating one as it enters the armature; this necessitates the use of brushes for a rubbing contact, and these require a good deal of attention from time to time for trimming and readjustment, and the commutators occasionally require turning up, and this pretty frequently if there is any sparking, which is often, if not always, the case, particularly when run in dirty and dusty places.

Now the polyphase motor does not require any commutator at all, and is thus freed from a very expensive and, at the best, a very undesirable part which is essential to the continuous-current motor.

Owing to the frailty of the continuous-current motor and the frequent sparking at the commutators, of late they have been made entirely enclosed; but this is undesirable, as it requires the motors to be larger and heavier for the same output, for the ventilation is not nearly so good as when open to the atmosphere, and, in addition, the various parts are not accessible.

With polyphase motors, and especially those with squirrel-

cage motors, there is absolutely no chance of the occurrence of a spark except at the starting switch, which may be placed at a distance from the motor. This is an important point when the motors are used in factories containing highly inflammable materials, or in fiery coal-mines.

The sizes of 3-phase motors are less and the weights lighter for the same power and efficiency than those of continuous-current motors, and as there are no exposed parts, such as brushes, &c., carrying the full voltage current and no adjustment required, the polyphase motor is simpler and consequently much more suitable to be left in the charge of an unskilled workman.

Seeing these many and great advantages of the polyphase system, it is not surprising that so many factories, both old and new, are now being equipped with this system of driving.

It is not many weeks since I heard one of the leading continuous-current engineers in the Midlands (and I believe he is here to-night) remark that even yet, with all the talk there is about the absolutely non-sparking, continuous-current motors, that he had great difficulty in getting a really satisfactory continuous-current motor, for he said, "Even those of the best and well-known makers, after he had had them running a few months or a year, showed their weak points and gave trouble."

It is often remarked that the polyphase system, although best adapted for motor driving, is not adapted for lighting. I do not think that any one would think of putting down a polyphase plant for lighting alone; but the advantages which it holds over other systems for motor-driving are much greater than the objections raised against it for lighting, and warrant its adoption in such places as factories, and my experience is that by distributing the lighting evenly between the phases that no difficulty whatever is experienced.

In America the induction motor has come more into general use than in this country, and I think it is very significant to note that such a firm as the Westinghouse Company, who make both polyphase and continuous-current machinery, have equipped their new works at Pittsburg with polyphase motors. Some 17 of the 60

induction motors replaced continuous-current motors which were originally put down to work the hoists.

In addition to those given in the list below, there are numerous other factories being driven by polyphase motors supplied with current from such large stations as the Niagara Plant and several large 3-phase power-distributing companies on the Pacific coast.

In Europe, too, there are many striking examples of polyphase factory plants, and those of us who attended the *réunion* in Switzerland two years ago will remember the Oerlikon Company's large engineering works at Zürich, where all kinds of electrical plant is built and where the whole works are driven by 3-phase motors. Originally three generators of 200 H.P. each were installed, but since then other two units of about 600 H.P. each, coupled to Sulzer engines, have been added, thus bringing the capacity of the plant up to about 1,800 H.P. There are 94 motors throughout the works, including some 18 cranes with a total lifting capacity of 220 tons. All of these are equipped with 3-phase motors. Messrs. Escher, Wyss & Co.'s works, also at Zürich, it will be remembered are driven throughout by about 100 3-phase motors.

The fine shops of Messrs. Brown, Boveri & Co., at Baden, too, many of us will remember, are driven by about 100 3-phase motors. Also the Alioth Electrical Company's new works at Münchenstein, near Bale, which are driven throughout by 3-phase motors.

I remember asking the managing director of these works his opinion as to continuous-current and polyphase motors, and was informed by him that they had a few continuous-current motors connected to a generator, only used to show to clients who preferred continuous current, and I was assured by him that they found the 3-phase plant by far the more preferable.

The number of factories driven by polyphase plants is much too great for them to be described here, but I have made a list of some of them, thinking it might be of interest to some of the members. This list, I regret to say, is not complete, but it is large enough, I think, to show that polyphase factory-driving, though somewhat uncommon in this country as yet, is by no means an experiment.

In addition to those given in the list of European plants, there are several very large works in Germany, some of which many of us are looking forward to see at the next *réunion* on the Continent in the course of a few months, notably those of the Allgemeine Elektricitäts Gesellschaft, at Berlin, which cover an area of 125,000 square yards, and in which some 14,000 people are employed, and where the whole of the machinery is driven by 3-phase motors, many of the tools being driven by separate motors. (They have about 700 motors in all.)

The list of examples of polyphase factory plants of which I have been able to get a few details, is much too long to read now, so I will only give a summary.

Summary of Examples.

United States of America	5	plants	aggregating	7,130	H.-P.
Sweden	2	"	"	4,105	"
Germany	15	"	"	7,685	"
Holland	1	"	"	450	"
Belgium	6	"	"	3,550	"
France	8	"	"	2,182	"
Spain	1	"	"	1,300	"
Switzerland	9	"	"	5,850	"
Austria	4	"	"	1,555	"
Italy	22	"	"	12,035	"
Russia	16	"	"	12,700	"
England	16	"	"	9,450	"
	105			68,192	

A brief description of some of the English polyphase plants may be of interest.

Liverpool Grain Elevator.—The first combined power and lighting plant was installed at Liverpool for the Grain Storage and Transit Company in the early part of 1897. It is a 3-phase plant of 180 H.-P. The lighting and power are both derived from the same circuits, and in spite of the antipathy to this practice, no difficulty has been experienced in the regulation.

Glasgow; Edinburgh.—About this time ('97) a small 3-phase plant of about 100 H.-P. was installed in Glasgow and another of about 130 H.-P. in Edinburgh.

Sir Thomas Richardson, Hartlepool.—In the same year Sir Thomas Richardson & Sons of Hartlepool laid down a large plant aggregating about 1,250 H.P. There are two large fly-wheel generators and a smaller machine of 100 k.w. for night shifts. In the shops are installed some 25 motors, which vary in size from 65 H.-P. to 10 H.-P.

General Electric Co., Manchester.—In 1898 the General Electric Co. of Manchester put in a 3-phase plant at their factory in the Adelphi, Salford. The generator is of 200 H.-P. and the motors, 30 in number, vary from 16 to ¼ H.-P.

Bristol Carriage and Waggon Co.—The Bristol Carriage and Waggon Co. about this time had their works remodelled, and a polyphase plant of 400 H.-P. was installed. There are 7 motor circuits, one to each shop, and the motors, 10 in number, vary from 65 to 2 H.-P. each. There are 750 glow-lamps and 32 arcs supplied from the same generator as the motors, and no difficulty has been experienced with the regulation. This plant has given such satisfactory results that another 400 H.-P. generating set is being added.

Anglo-Swiss Milk Co., Aylesbury.—The Anglo-Swiss Condensed Milk Co.'s factory at Aylesbury is equipped with a 3-phase plant. The 8 motors installed vary in size from 10 to 1½ H.-P. each.

North-Eastern Steel Works, Middlesboro'.—At the North-Eastern Steel Works, Middlesboro', there is a 2-phase plant consisting of 2 generators of 350 H.-P. each, and 11 motors—6 of 40 H.-P., 5 of 20 H.-P.

D. Y. Stewart, Glasgow.—Messrs. D. Y. Stewart, of Glasgow, have a 3-phase plant of 450 H.-P., consisting of 2 generators of 250 and 200 H.-P., and a large number of motors.

Beyer & Peacock, Manchester.—Messrs. Beyer & Peacock, of Manchester, have a 3-phase plant of 400 H.-P., consisting of 2 generators of 200 H.-P. each, and a large number of motors of 50, 30, and 20 H.-P. each.

Hawthorn & Leslie, Newcastle-on-Tyne.—Messrs. Hawthorn & Leslie, of Newcastle-on-Tyne, have a 3-phase

plant of 280 H.-P. for driving the machines in their shipyard.

W. Dixon & Co., Glasgow.—Messrs. Dixon & Co., of Glasgow, have a 3-phase plant of 660 H.-P., consisting of three generators of 220 H.-P. each, and a large number of motors for various purposes in their chemical works.

Kirkstall Forge, Leeds.—The Kirkstall Forge Company, of Leeds, have a 150 H.-P. 3-phase plant in their works.

Brown, Marshall, Birmingham.—Messrs. Brown, Marshall & Co., of Birmingham, have a small 3-phase plant of about 70 H.-P. in their carriage and waggon building works, for driving the machinery in one of their shops.

J. Thompson, Wolverhampton.—Messrs. John Thompson, boiler makers, Wolverhampton, have recently installed a 3-phase plant of 460 H.-P., consisting of two direct-coupled steam alternators of 230 H.-P. each, and a corresponding number of motors.

J. Rogers & Sons, Sheffield.—Messrs. Jos. Rogers & Son have recently installed in their large cutlery works in Sheffield a 2-phase plant of 320 H.-P., consisting of two direct-coupled high-speed generators of 160 H.-P. each. These alternators have only 8 poles each, which give the low frequency of 21·3 cycles per second. There are 7 motors of 25 to 7 H.-P. each, used for working grinding wheels, hoists, fans, stamps, &c. Owing to the low frequency a motor generator is used for arc lighting.

Patent Shaft.—Whilst at the Patent Shaft & Axletree Company's Works at Wednesbury we have a plant of 420 H.-P., consisting of 2 3-phase generators of 210 H.-P. each, and some 30 motors, varying in size from 50 H.-P. to 5 H.-P., the small ones being in use on travelling cranes.

As I am connected with this plant, perhaps I can give a few details of it which may be of interest.

The power-house, which was built to the designs of the author, comprises boiler-house, engine-room, and the necessary offices, stores and test-room, and is large enough to accommodate 2,000 H.-P.

In the boiler-house are 4 of Messrs. Babcock & Wilcock & Co.'s water-tube boilers, of 200 H.-P. each, also a feed-water heater by the same firm. The boiler-house is so arranged that the coal is tipped direct from the railway siding into the bunker opposite the fronts of the boilers.

These are fed by either a horizontal duplex Tangye's pump, or a Gresham & Craven line steam injector, which deliver either through the above-mentioned heater or direct into the boilers.

The generating plant consists of two direct-coupled sets of 210 H.-P. each, running at 375 revolutions per minute. The engines are of the compound two-crank, single-acting enclosed type by Mirrlees, Watson & Yaryan. The generators are of the well-known Brown, Boveri & Co.'s 3-phase type, having rotating fields and stationary armatures, the periodicity being 50, and the voltage across the phases 350, They are "star" connected with a neutral terminal, which, as already stated, serves for the lighting both arc and incandescent lamps at 200 volts. The exciters are direct driven, their armatures being fixed on an extension of the generator shaft.

The switchboard which is fixed on a gallery commanding a view of the whole engine-room, consists of two generator panels carrying main triple pole switch and fuse, ammeter, voltmeter and field rheostat, the latter being of the Ward Leonard make, one synchronising panel, having synchronising apparatus, main voltmeter, with 3-way switch for throwing the voltmeter across any of the 3 phases, a recording voltmeter and fuses for the neutrals of four generators, two feeder panels each carrying two sets of triple pole switches and fuses, and two ammeters, two lighting panels, each carrying one 4-pole switch and three ammeters one being for each phase.

The panels are of polished marble, supported on an iron framing, placed 4 feet from the wall, while a glass roof and end doors keep out dust, &c., from the connections and terminals, and provide easy access to the back with a good light.

The main cables or feeders are of the British Insulated Wire Company's make, and are drawn into Doulton conduits, the power mains having 3 twisted cores, while the lighting mains have 4 cores, the fourth being for the neutral return. The sizes of these cores vary from $\frac{37}{12}$ to $\frac{19}{15}$. These feeders run from the main switchboard to distributing switchboards fixed in sub-stations at various points in the works. These distributing switchboards carry six power and six lighting sub-circuits each, with triple pole

switches and fuses for the power, and single pole switches and fuses for the lighting. There are separate bars for power and lighting which can, in case of emergency, be interconnected by means of plugs, thus providing for supplying the bus-bars from either power or lighting feeders. A neutral bar is provided to which each lighting sub-circuit is connected, and in each sub-station the lighting circuits are balanced as nearly as possible. The sub-circuits consist of similar cables to the feeders, and are also drawn into Doulton conduits, triple-core for the motors and two-core for the lighting.

The motors have been arranged to replace separate engines, and to drive on to the existing shafting in order that no disturbance might be made in converting to the new system. The lines of shafting in most cases have been split up so as to be driven in smaller groups for greater economy.

I may here remark that the whole of the transfer was effected without stopping any of the workshops.

One of the Goliath cranes has been converted from steam to electricity, the motor replaced the boiler and engine which were previously used. The reducing gear consists of a raw-hide pinion fixed on the motor shaft of the crane, which operates the various motions. The motor controller is of the Brown, Boveri Co.'s type, and consists of a reversing switch connected in the stator circuit and controlling resistance in the rotor circuit. These switches are interlocked, and the whole controlled by one lever, so that the motor is started, the speed controlled, and the direction of rotation is reversed by the movement of this one lever.

The motor derives its current from 3 trolley wires fixed on the usual overhead system.

In the foundry are two new electric travelling cranes, each operated by 3 motors. One is for a maximum of 20 tons, and has 2 motors of 10 H.-P. each, and 1 of 5 H.-P., the other is a 5-ton crane and has 2 motors of 7 H.-P., and 1 of 3 H-.P. The two larger motors are in each case for lifting and longitudinal motions, and are provided with controlling rheostats for reducing the speed.

As a result of experience 10 additional cranes are now being fitted with 3-phase motors and controllers, and

another generating set of 500 H.-P. is being erected in the power-house.

The lighting of the works is done by some 500 glow-lamps and 60 arc lamps; the latter are run six in series on the 200-volt mains, and no difficulty has been experienced in the regulation, although the lighting is taken from the same generators as the motors. The whole of the wiring for the lighting is enclosed in "Simplex" steel conduits.

Since the plant was started over a year ago, it has worked most successfully. The economy has been very marked, and will show still better results when all the cranes which are now being converted are electrically driven, and the new plant is in operation.

During the recent inquiry of the Parliamentary Committee upon the Electric Power Bills there was a good deal said about the effect of a good load factor upon the cost of generation of electricity.

As is to be expected, we get a very good all-day load on my station, and instead of getting a load factor of 11·05 per cent., which is the *average* of all the supply stations given in "Lightning's" table of costs, the load factor for the past year on our station was 42·01 per cent.; and with an output of 554,000 B.T.U. per year the works cost of generation, viz., coal, water, wages, oil and stores, work out to the remarkably low figure of ·552d. per unit, whilst the cost of distribution, *i.e.*, the motor attendants, crane men, and arc lamps trimmer, &c., works out at ·215d., so that the works cost of the energy delivered at the shafting or machines is ·552d. and ·215d. = ·767d. per B.T.U. I do not mean that this low figure is necessarily due to the plant being polyphase, but I thought that this data would be interesting inasmuch as it bears out in such a marked degree the effect of the load factor on the costs.

Bolckow, Vaughan & Co.—As a further sign of the growth of favour for polyphase plants in the country, I may mention that Messrs. Bolckow, Vaughan & Co., the large iron masters, are now erecting a power-station at Eston, near Middlesboro', for the driving of their works and the lighting of the town, and this is to be on the 3-phase system.

The size of the first generating sets, of which two or three are being installed, is 1,500 H.-P. each.

It is seen, then, that since the introduction of polyphase factory equipment into this country in 1897, there have been no less than 16 installations started, amounting in the aggregate to about 10,000 H.-P.

I venture to think that the growth to this amount of a system in its first four years in this very conservative country of ours promises well for its success and development in the future.

APPENDIX.

Examples of Polyphase Equipments in Factories.

Name.	Place.	Factory.	System.	$\sim$	Generating Plant.	Total Horse-Power.	Number and Size of Motors.	How Employed.	Remarks.
Pelzer Manufacturing Company	South Carolina, U.S.A.	Cotton Spinning and Weaving...	3-phase	40	3 1,000 H.P. Alternators ...	3,000	15 of 110 H.P. ... 4 of 75 H.P. ... 2 of 50 H.P. ... 4 of 5 H.P.	Driving line shafting. Small ones direct coupled to Pumps and Fans.	
Westinghouse Company ...	East Pittsburg ...	Electrical Engineering ...	2-phase	25	3 500 H.P. Alternators... ...	1,500	57	Shafting and hoists	These Works employ 4,000 hands.
Pommah Mills ...	Taftville, Connecticut	Cotton Spinning	3-phase	50	2 335 H.P. Alternators... ...	670	2 Synchronous ...	Driving Shafting	These Motors are self-starting.
Columnia Cotton Company ...	Columbia, South Carolina ...	Cotton Spinning	3-phase	36	2 680 H.P. Alternators... ...	1,360	20 of 65 H.P. ...	Driving Shafting	All these Motors are on ceilings.
Simmonds Saw Mills	Fitchburg, Massachusetts ...	Saw Mills ...	2-phase	50	1 600 H.P. Alternator	600	11	Driving Shafting	This Plant is being extended.
Killner Partington Paper Pulp Company	Sarpsborg, Sweden	Paper Manufacturing	3-phase	...	1 400 H.P. Alternator ... ... 1 600 H.P. Alternator ... ... 2 1,500 H.P. Alternators ...	4,000	1 of 200 H.P., etc....	Driving Shafting	The 2 1,500 H.P. units are for the manufacture of Calcium Carbide.
Nyhmmars Bruk	Sweden	...	3-phase	...	1 105 H.P. Alternator	105	1 of 75 H.P. ...	Driving Shafting.	
Eisenhutten Aktienverein Düdelingen	Luxemburg ...	...	3-phase	...	2 600 H.P. ... 2 1,000 H.P. ...	3,200	Many of various H.P.	Driving Pumps, Fans, Cranes, etc.	
Antonienhütte ...	Silesia, Germany	Zinc Smelting and Fire Bricks ...	3-phase	...	2 300 H.P. ...	600	Many of various H.P.	Driving Pumps, Fans, Cranes, etc.	Used both above and below ground.
Edlerschacht Station	Germany ...	Mine	3-phase	...	1 500 H.P. ...	500	1 of 350 H.P. ...	Pumping.	

Paper Pulp Company	Albbruck, Germany	Paper Pulp Works	3-phase	...	1 500 H.P. ...	500	1 of 400 H.P. and several smaller ...	Driving Shafting.	
Cotton Spinning Company ...	Arlen, near Singen	Cotton Spinning and Weaving ...	2-phase	...	2 225 H.P. ...	450	Several of 180, 100 H.P., etc.	Driving Shafting.	
Mechanical Weaving Company ...	Jourdain, Attkirech, Alsace ...	Weaving Works	3-phase	...	2 175 H.P. ...	350	Several of various H.P.	Driving Shafting.	
Duméril Jaeglé & Co.	Thann, Alsace ...	...	3-phase	...	1 300 H.P. ...	300	Large number of small motors ..	Driving Shafting.	
F. & Th. Frey ...	Guebwiller ...	Spinning and Weaving Mills	3-phase	...	1 250 H.P. ...	250	Group driving by a number	...	
Dr. A. Feer Ernst	Lärrach, Brombach	Cloth Print Works	3-phase	50	...	...	Large number of motors	Group driving ...	Current from Rheinfelden.
Waiblingen & Etablissement Hurzog	Logelbach, near Colmar... ...	Broad Silk Weaving	3-phase	...	...	...	Number of small motors	Special method of driving Looms.	
Gutter Tile Factory	Bexbach, Mittelbexbach ...	Gutter Tile ...	3-phase	...	1 80 H.P. ...	80	Number of small motors	Driving Machines	Also two 3-phase Locomotives.
Adolphütte ...	Near Bautzen ...	Brick Factory ...	3-phase	...	1 125 H.P. ...	125	5 10 to 60 H.P. ...	Driving Presses, Pumps, etc.	
Bergverwaltung ...	Raibl	Mine	3-phase	...	...	...	1 of 65 H.P. ... ... 1 of 35 H.P. ... ... 1 of 12 H.P. ... ... 1 of 6 H.P.	Driving Pumps... Shaft Elevator ... Centrifugal Pumps... ... Submerged Pumps... ...	Current from Public Supply.
Röchling Works ...	Diedenhofen ...	Iron and Steel Works	3-phase	...	1 180 H.P, Alternator ... ... 1 650 H.P. Alternator	830	Several of various H.P.	Driving Elevators and Pumps ...	Also Machines at two pits some distance away. Provision is made for three Generators of 650 H.P.
P. Schweryer & Co.	Nerdingen, Germany	Sugar Refining ...	3-phase	...	2 225 H.P. ...	500	94 of 1 to 5 H.P. ...	Direct coupled to Centrifugal Machines.	
Royal Dutch Company	Maastricht, Holland	Paper Manufacture	3-phase	...	1 450 H.P. ...	450	Several	Driving Machines.	

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Examples of Polyphase Equipments in Factories.

Name.	Place.	Factory.	System.	∿	Generating Plant.	Total Horse-Power.	Number and Size of Motors.	How Employed.	Remarks.
Pelzer Manufacturing Company	South Carolina, U.S.A.	Cotton Spinning and Weaving...	3-phase	40	3 1,000 H.P. Alternators ...	3,000	15 of 110 H.P. ... 4 of 75 H.P. ... 2 of 50 H.P. ... 4 of 5 H.P.	Driving line shafting. Small ones direct coupled to Pumps and Fans.	
Westinghouse Company ...	East Pittsburg ...	Electrical Engineering ...	2-phase	25	3 500 H.P. Alternators... ...	1,500	57	Shafting and hoists	These Works employ 4,000 hands.
Pommah Mills ...	Taftville, Connecticut	Cotton Spinning	3-phase	50	2 335 H.P. Alternators... ...	670	2 Synchronous ...	Driving Shafting	These Motors are self-starting.
Columnia Cotton Company ...	Columbia, South Carolina ...	Cotton Spinning	3-phase	36	2 680 H.P. Alternators... ...	1,360	20 of 65 H.P. ...	Driving Shafting	All these Motors are on ceilings.
Simmonds Saw Mills	Fitchburg, Massachusetts ...	Saw Mills ...	2-phase	50	1 600 H.P. Alternator	600	11	Driving Shafting	This Plant is being extended.
Killner Partington Paper Pulp Company	Sarpsborg, Sweden	Paper Manufacturing	3-phase	...	1 400 H.P. Alternator ... ... 1 600 H.P. Alternator ... ... 2 1,500 H.P. Alternators ...	4,000	1 of 200 H.P., etc....	Driving Shafting	The 2 1,500 H.P. units are for the manufacture of Calcium Carbide.
Nyhmmars Bruk	Sweden	...	3-phase	...	1 105 H.P. Alternator	105	1 of 75 H.P. ...	Driving Shafting.	
Eisenhutten Aktienverein Düdelingen	Luxemburg ...	...	3-phase	...	2 600 H.P. ... 2 1,000 H.P. ...	3,200	Many of various H.P.	Driving Pumps, Fans, Cranes, etc.	
Antonienhütte ...	Silesia, Germany	Zinc Smelting and Fire Bricks ...	3-phase	...	2 300 H.P. ...	600	Many of various H.P.	Driving Pumps, Fans, Cranes, etc.	Used both above and below ground.
Edlerschacht Station	Germany ...	Mine	3-phase	...	1 500 H.P. ...	500	1 of 350 H.P. ...	Pumping.	

Paper Pulp Company ...	Albbruck, Germany ...	Paper Pulp Works	3-phase	...	1 500 H.P. ...	500	1 of 400 H.P. and several smaller ...	Driving Shafting.	
Cotton Spinning Company ...	Arlen, near Singen ...	Cotton Spinning and Weaving...	2-phase	...	2 225 H.P. ...	450	Several of 180, 100 H.P., etc. ...	Driving Shafting.	
Mechanical Weaving Company ...	Jourdain, Altkirech, Alsace ...	Weaving Works	3-phase	...	2 175 H.P. ...	350	Several of various H.P. ...	Driving Shafting.	
Duméril Jaeglé & Co. ...	Thann, Alsace ...	...	3-phase	...	1 300 H.P. ...	300	Large number of small motors ..	Driving Shafting.	
F. & Th. Frey ...	Guebwiller ...	Spinning and Weaving Mills	3-phase	...	1 250 H.P. ...	250	Group driving by a number ...	...	
Dr. A. Feer Ernst	Lärrach, Brombach ...	Cloth Print Works	3-phase	50	...	...	Large number of motors ...	Group driving ...	Current from Rheinfelden.
Waiblingen & Etablissement Hurzog ...	Logelbach, near Colmar...	Broad Silk Weaving ...	3-phase	...	...	...	Number of small motors ...	Special method of driving Looms.	
Gutter Tile Factory ...	Bexbach, Mittelbexbach ...	Gutter Tile ...	3-phase	...	1 80 H.P. ...	80	Number of small motors ...	Driving Machines	Also two 3-phase Locomotives.
Adolphütte ...	Near Bautzen ...	Brick Factory ...	3-phase	...	1 125 H.P. ...	125	5 10 to 60 H.P. ...	Driving Presses, Pumps, etc.	
Bergverwaltung ...	Raibl	Mine	3-phase	...	...	...	1 of 65 H.P. ... ... 1 of 35 H.P. ... ... 1 of 12 H.P. ... ... 1 of 6 H.P.	Driving Pumps... Shaft Elevator ... Centrifugal Pumps... ... Submerged Pumps... ...	Current from Public Supply.
Röchling Works ...	Diedenhofen ...	Iron and Steel Works ...	3-phase	...	1 180 H.P, Alternator ... ... 1 650 H.P. Alternator	830	Several of various H.P. ...	Driving Elevators and Pumps ...	Also Machines at two pits some distance away. Provision is made for three Generators of 650 H.P.
P. Schweryer & Co.	Nerdingen, Germany ...	Sugar Refining ...	3-phase	...	2 225 H.P. ...	500	94 of 1 to 5 H.P. ...	Direct coupled to Centrifugal Machines.	
Royal Dutch Company ...	Maastricht, Holland ...	Paper Manufacture ...	3-phase	...	1 450 H.P. ...	450	Several	Driving Machines.	

EXAMPLES OF POLYPHASE EQUIPMENTS IN FACTORIES (*continued*).

Name.	Place.	Factory.	System.	∿	Generating Plant.	Total Horse-Power.	Number and Size of Motors.	How Employed.	Remarks.
Société des Usines Rémy	Wygmael, near Lourain ...	Starch Making ...	3-phase	...	1 150 H.P. Belt-driving Alternator ... ... 1 300 H.P. Fly-wheel Alternator ... ... 1 600 H.P. Fly-wheel Alternator	1,050	Several of various sizes	Shaft driving, also Centrifugal Machines.	
Société Anonyme, "La Louisiane"	Ghent, Belgium...	Spinning Factory	3-phase	...	1 500 H.P. Rope driven... ...	500	Several of various sizes	Group driving.	
Compagnie Générale d'traction Electrique ...	Brussels	Canal Navigation	3-phase	...	2 350 H.P. Rope driven... ... 3 100 H.P. Rope driven... ...	1,000	60 of 5 to 10 H.P. ...	Working small Locomotives.	
Société Anonyme des Charbonnages Espérance et bonne Fortune	Montegnec - les-Liége	Mine	3-phase	...	2 300 H.P. Fly-wheel	600	Several	Mining work.	
Usine de Désargentation	Hoboken-les-Anvers	...	3-phase	...	1 250 H.P. Gas Engine ...	250	Several	Driving Shafting.	
Société Anonyme, John Cockerill ...	Seraing, Belgium	...	3-phase	...	1 150 H.P. Belt driven from Gas Engine ...	150	2 of 60 H.P. ... ... 1 of 120 H.P. ...	Driving Cement Works and Shafting ...	Blast Furnace Gas Engine.
Motte Dewavrin Mill	Tourcoing, France	Spinning Mills ...	3-phase	...	1 325 H.P. Rope driven ... 1 20 H.P. Belt driven... ...	345	Several	Driving Spinning Machinery.	
Lorthiois Brothers	Tourcoing, France	Weaving Mills ...	3-phase	...	1 120 H.P. Direct driven... ... 1 27 H.P. Belt driven... ...	147	Several 1 H.P. ...	Independent driving heavy Damask Looms.	
A. Bouchon ...	Nassandres (Eure)	Sugar Factory ...	3-phase	...	1 250 H.P. ... 1 90 H.P. ...	340	Many Motors ...	Driving whole Machinery.	
Aciéries de France	Isbergues (Pas de Calais)	Engineering Works	2-phase	...	1 300 H.P. ...	300	Many Motors ...	Machines, Tools, etc.	

Phillipe Bunan Varilla	Paris	...	3-phase	...	1 150 H.P. ...	150	Several	Machinery, also a Dredger.	
Weyher and Richmond	Pantin (Seine) ...	Engineering Works	2-phase	40	4 150 H.P. ...	600	17 50 H.P. down to 3 H.P.	Machinery, Cranes, etc.	
Aubrives and Villerupt	Meurthe and Moselle ...	Engineering Works	2-phase	...	2 150 H.P. ...	300	...	Machinery, Cranes, etc.	
Gillet et Fils ...	Villeurbanne, near Lyons	Dyeing and Finishing	3-phase	...	...	...	Large number ...	Independent and group driving of Mangles, etc.	Current obtained from Société Lyonnaise des Forces Matrices du Rhone.
Mining and Metallurgical Company	Horcajo, Spain ...	Mine	3-phase	...	3 300 H.P. Belt driven... ... 1 400 H.P. Direct driven... ...	1,300	4 of 250 H.P... ...	Centrifugal Pumps ...	These pumps lift water 500 m.
Oerlikon Company	Zurich, Swisse ...	Engineering Works	3-phase	...	3 200 H.P. ... 2 600 H.P. ...	1,800	94 Various sizes ...	Machines, Tools, Cranes, etc.	
Escher Wyss & Co.	Zurich, Swisse ...	Engineering Works	3-phase	...	...	...	100 Various sizes ...	Machines, Tools, Cranes, etc.	
Brown Boveri & Co.	Baden, Swisse ...	Engineering Works	2-phase	...	3 150 Belt driven	450	100 ½ to 100 H.P. ...	Machines, Tools, Cranes, etc.	
Von Roll Iron Works	Gerlafingen, Swisse	Iron Works ...	3-phase	...	2 150 H.P. ...	300	Several	Driving Machines and Tools.	
Von Roll Iron Works	Rondez	Iron Works ...	3-phase	...	2 175 H.P. ...	350	Several	Driving Machines and Tools ...	
Alioth Electrical Company ...	Münchenstein, near Bâle ...	Engineering Works	3-phase	...	...	...	Several	Driving Machines and Tools.	
Von Moos Iron Works	Lucerne	Iron Works ...	2-phase	...	400 H.P.... ...	400	Several 200, 120 H.P., etc.	Direct driving of Rolling Mills...	Current also obtained from Rathausen Central Station.
Pott Spärry ...	Flums	Calcium Carbide	3-phase	...	3 800 H.P. ... 1 50 H.P. ...	2,450	Several	Preparing and Crushing Plant and Furnaces	18 Furnaces each capable of absorbing 150 k.w.
Bally and Sons ...	Schoenenwerd ...	Boot and Shoe ...	3-phase	20	1 100 H.P. ...	100	10 of 10 H.P. downwards	Driving Shafting	
E. Skoda	Pilsen, Austria ...	Steel Foundry ...	3-phase	...	...	650	Several of various H.P.	Driving high-speed Foundry Cranes.	

EXAMPLES OF POLYPHASE EQUIPMENTS IN FACTORIES (*continued*).

Name.	Place.	Factory.	System.	∿	Generating Plant.	Total Horse Power.	Number and Size of Motors.	How Employed.	Remarks.
Brigl and Bergmeister	Nicklasdorf, Austria... ...	Paper Factory ...	3-phase	...	1 165 H.P. ...	165	1 130 H.P.	Driving Wood Grinders.	
Spinning Mills ...	Vöslau, Austria ...	Worsted Spinning	3-phase	...	1 240 H.P. ...	240	Several of various H.P.	Driving Shafting	
Seigkam Jasefthal	Austria	Paper Factory ...	3-phase	...	2 250 H.P. ...	500	6 of 3 to 106 H.P. ...	Driving Shafting	
Reali Mill	Treviso, Italy ...	Paper Mill ...	3-phase	...	2 200 H.P. ...	400	Several 160, 90, 70, H.P., etc.	Driving Shafting	
Vonwiller & Co. ...	Romagnano Sesia, Italy	Paper Mill ...	2-phase	...	3 275 H.P. ... 1 300 H.P. ...	1,125	6 of 120 H.P. ... 1 of 200 H.P. ... and many smaller ...	Driving Shafting	
Wild and Abegg ...	Turin, Italy ...	Spinning Mills ...	3-phase	...	1 880 H.P. ... 1 450 H.P. ...	1,330	300, 200, 150, and 50 H.P.	Lighting and Driving Mills	
Frua Banfi & Co...	Legnano, Italy ...	Spinning Mills ...	3-phase	...	...	2,200	600, 500, 400, 330, 250, and 125 H.P. motors	Lighting and Driving Mills	Current from Vizzola Central Station.
Ing. Muggiani Company ...	Intra, Italy ...	Spinning Mills ...	3-phase	...	...	720	300, 200, 120, and 100 H.P...	Lighting and Driving Mills	Run off Ossolana and Intra Supply Stations.
Nine Spinning Mills	Como, Italy ...	Silk Spinning ...	3-phase	...	...	...	Great number small motors	Independent driving of Silk Looms ...	Current from Supply Station.
Manifattura Festi Rasini	Villa d'Ogna, Italy	Spinning Mill ...	...	...	2 280 H.P. ...	560	2 of 230 and 150 H.P.	Driving and Lighting Mills.	
Fratelli Visocchi ...	Atina, Italy ...	Paper Mill ...	3-phase	...	1 600 H.P. ...	600	280, 200, and 40 H.P.	Driving and Lighting Mills.	
Egidio and Pio Gavazzi	Desio, Italy ...	Silk Spinning ...	2-phase	...	2 250 H.P. ... 1 430 H.P. ...	930	2 of 120 H.P. ... 300 small motors ...	Small motors for Direct driving of Looms.	
Leger Hefti ...	Ponte St. Pietro, Italy	...	3-phase	...	2 380 H.P. ...	760	2 Slow-speed 300 H.P.	...	Speed of Motors 200 R.P.M.
Niggeler and Küpfer	Palazzolo sull' Oglio	...	3-phase	...	2 300 H.P. ...	600	250, 150, 50, and many smaller motors ...	Driving Mills.	
Fubter Bébié ...	Gravellona - Toce	...	3-phase	...	1 225 H.P. ...	225	1 120 H.P. ... ... 1 40 H.P., etc. ...	Lighting and Driving Mill.	
Ant. and And. Ponti	Solbiate Olona ...	Weaving Factory	3-phase	...	1 220 H.P. ...	220	80, 30, and 6 H.P. ...	Group driving.	

Francesco Rossi ...	Perale	Paper Factory ...	3-phase	...	1 400 H.P. ... 1 175 H.P. ... 1 150 H.P. ...	725	2 of 140 H.P.... ... 1 of 200 H.P.... ... Many smaller ...	Machine driving.	
Gioachino Zopfi ...	Bergamo	Cotton Spinning	3-phase	...	1 300 H.P. ...	300	Large number ...	Machine driving.	
Ernesto Ceriana ...	Frassinetto-Po ...	Cement Works ...	3-phase	...	1 220 H.P. ...	220	1 90 H.P. and smaller motors	Lighting and driving.	
Salesiana Mill ...	Mathi, Italy ...	Paper Mill ...	3-phase	...	1 210 H.P. ...	210	1 170 H.P. motor ...	...	
G. Marzotto and Sons	Valdagno... ...	Spinning Mills ...	3-phase	...	1 180 H.P. ... 1 150 H.P. ...	330	2 of 140 H.P.... ...	Lighting and driving.	
Biancho & Co. ...	Intra	Spinning Mills ...	3-phase	...	...	200	1 200 H.P.	Lighting and driving ...	Current from Intra Central Station.
Ernesto Breda & Co.	Milan	...	3-phase	...	1 120 H.P. ...	120	Several	Driving Works	
Fraschini and Porta	Brescia	...	3-phase	...	1 120 H.P. ...	120	Several	Driving Works.	
V. Bass & Co. ...	Turin	Cotton Spinning	3-phase	...	1 150 H.P. ...	150	1 120 H.P.	Driving Works.	
Procharoff and Sons	Moscow	Weaving Mills ...	3-phase	...	1 1,000 H.P. ... 1 1,600 H.P. ...	2,600	Large number various sizes ...	Single and group driving.	
Baranoff Works ...	Karabanowe ...	Spinning and Cloth Printing	3-phase	...	1 1,600 H.P. ...	1,600	Large number various sizes ...	Single and group driving.	
Balaschinskaya Manufactur ...	Moscow	...	3-phase	...	1 1,600 H.P. ... 1 200 H.P. ...	1,800	140, 70, 40, 15, and 5 H.P.	Single and group driving.	
Water Works ...	Moscow	...	3-phase	...	1 250 H.P. Rope driven... ... 2 325 H.P. Direct driven... ...	900	20 of 20 H.P. ...	...	The Motors are of special design for coupling to vertical Pumps.
Alagir Mining and Chemical Company	Darg Koch, Caucasus	Mining and Chemical ...	3-phase	...	2 of 250 H.P. ...	500	Large number of Motors	Ore washing and Pit driving.	
Twarskaya Manufactur	Twer, Russia ...	...	3-phase	...	1 450 H.P. Fly Wheel Alternator	450	Large number of Motors	Driving Shafting.	
Wladikawkas Railway Company ...	Port of Noworosiska	...	3-phase	...	4 250 H.P. ...	1,000	Large number of Motors	Driving Conveyors, Lifts, Cranes, etc.	
Riasan Ural Railway Company ...	Tamboir Station	Railway Shops ...	3-phase	...	2 360 H.P. Fly Wheel ...	720	Large number of Motors	Driving Lathes, Machine Tools, etc.	
Nicolai Railway Company ...	Alexandrow, St. Petersburg ...	Railway Shops ...	3-phase	...	1 330 H.P. ...	330	Large number of Motors	Driving Lathes, Machine Tools, etc.	

EXAMPLES OF POLYPHASE EQUIPMENTS IN FACTORIES (*continued*).

Name.	Place.	Factory.	System.	∿	Generating Plant.	Total Horse Power.	Number and Size of Motors.	How Employed.	Remarks.
Zimin Mills ...	Dresna	Spinning and Weaving ...	3-phase	...	3 210 H.P. ...	630	Large number of Motors	Driving Looms.	
Tube Rolling Mills	St. Petersburg ...	Tube Rolling ...	3-phase	...	3	540	Large number of Motors	Driving Rolling Mills and Machine Tools, and Lighting.	
Bromley Engine Works	Moscow	Engineering ...	3-phase	...	1 350 H.P. ...	350	Large number of Motors	Driving Shops.	
Brass and Copper Rolling Mills ...	Koltschugin, Kel-lerowo	Brass and Copper	3-phase	...	1 300 H.P. ...	300	Large number of Motors	Driving Mills.	
Tschetwerikow Factory	Porodischtschi ...	Cloth making ...	3-phase	...	1 300 H.P. ...	300	Large number of Motors	Driving Mills.	
Sisterbeck Rifle Factory	Sisterbeck ...	Rifles and Ammunition ...	3-phase	...	1 60 H.P. ... 1 20 H.P. ...	80	Number of small Motors of 7, 1, 2, 3, 10, and 20 H.P.	Separate Driving of Machine Tools.	
Colomna Engine Works	Russia	Engineering ...	...	...	...	600	Large number ...	Separate Driving of Machine Tools.	
Grain Storage and Transit Company	Liverpool ...	...	3-phase	...	1 180 H.P. ...	180	2 18 H.P. ... ... 1 60 H.P. ... ... 1 26 H.P. ... ... 3 5 H.P. ... ... 1 3 H.P.	Driving Conveyors and Lighting Sheds.	
Sir Thomas Richardson and Sons	Hartlepool ...	Engineering ...	3-phase	41	2 420 H.P. ... 1 120 H.P., etc.	1,250	25 Motors of 60, 45, 25, etc., H.P. ...	Driving Shops.	
General Electric Company, Ltd.	Manchester ...	Electrical Engineering ...	3-phase	45	1 200 H.P. ...	200	30 of 36 to ½ H.P. ...	Single and group driving.	
Bristol Carriage and Wagon Company ...	Bristol	Carriage and Wagon Works	3-phase	50	1 400 H.P. Rope driven... ... 1 400 H.P. Direct driven... ...	800	10 of 65 to 2 H.P. ...	Shop driving.	
Anglo Swiss Condensed Milk Company, Ltd.	Aylesbury ...	Dairy	3-phase	...	...	...	8 of 10 to 1½ H.P. ...	Driving Dairy Machines.	

North Eastern Steel Works ...	Middlesbrough	Iron and Steel ...	2-phase	40	2 350 H.P. Direct coupled, slow speed ...	700	6 of 40 H.P. ... ... 5 of 20 H.P.	Driving Machine Tools, Cranes, etc.	
D. T. Stewart & Co.	Glasgow	...	3-phase	...	1 250 H.P. ... 1 200 H.P. ...	450	...	...	
Beyer and Peacock & Co., Ltd. ...	Manchester ...	Engineering ...	3-phase	...	2 200 H.P. ...	400	50, 30, and 20 H.P. etc.	Driving Machine Tools, Cranes, etc.	
Hawthorne Leslie & Co.	Newcastle-on-Tyne	Engineering ...	3-phase	...	1 280 H.P. ...	280	Many Motors ...	Driving Machine Tools in Shipyard.	
W. Dickson & Co.	Glasgow	Chemical Works	3-phase	...	3 220 H.P. ...	660	Large number ...	Driving Machines.	
James Rogers & Sons	Sheffield	Cutlery	2-phase	21·3	2 160 H.P. Direct Coupled, High Speed	320	2 of 25 H.P. ... ... 1 of 22 H.P. ... ... 2 of 12 H.P. ... ... 1 of 7 H.P. ... ... 1 of 5 H.P.	Driving Grinding Wheels, Hoists, Fans, etc.	Owing to low frequency motor-generator is used for arc-lighting.
John Thompson ...	Wolverhampton	Boiler Works ...	3-phase	...	2 230 H.P. ...	460	Several	Driving Shafting.	
Kirkstall Forge Company ...	Leeds	Forge	3-phase	...	1 150 H.P. ...	150	Several	Driving Shafting.	
Patent Shaft and Axletree Co., Ltd.	Wednesbury ...	Bridge building and Engineering	3-phase	50	2 210 H.P. High Speed Direct Coupled ... 1 500 H.P. High Speed Direct Coupled ...	920	2 of 50 H.P. ... 2 of 40 H.P. ... 3 of 30 H.P. ... 13 of 20 H.P. ... 6 of 10 H.P. ... 2 of 7 H.P. ... ... 2 of 5 H.P. ... ... — 30	Single and Group driving Machinery, Cranes, Hydraulic Pumps, etc., also Lighting.	
Brown, Marshall & Co., Ltd. ...	Birmingham ...	Carriage and Wagon Works	3-phase	45	1 70 H.P. ...	70	1 40 H.P.	Driving Shafting.	
Fletcher, Russell & Co.	Warrington ...	Engineering ...	3-phase	...	2 80 H.P. ...	160	2 20 H.P., etc. ...	Direct driving Roots' Blowers, and Machine Driving.	
Bolckow, Vaughan & Co.	Middlesbrough	Iron and Steel Works	3-phase	...	2 1,500 H.P. ...	3,000	Several	Driving Shops, etc.	In course of erection.

Mr. Unwin-Sowter.

Mr. W. J. UNWIN-SOWTER (*communicated*): My experience of motive-power supply from single-phase alternating plant leads me to believe that such undertakings are at enormous disadvantage as compared with continuous-current supply on account of the low power-factor. I have lately tested about a dozen small motors arranged for driving small tools, etc., from a single-phase alternating supply of about 85 $\sim$ and 200 volts, and find the power-factor even less than that stated by the makers. To give examples :—

(1) 1 *H.P. motor, English make.*

No load (without belt).—Starting current, 9 amperes; running current, 6·3 amperes at 200 volts; true watts, 282; apparent watts, 1,260; ratio, 22·4 per cent.

Full load.—Current, 9 amperes at 193 volts; true watts, 773; apparent watts, 1,775; ratio, 43·6 per cent.

(2) 2 *H.P. motor.*

No load.—Starting current, 20 amperes; running current, 10 amperes at 202 volts; true watts, 564; apparent watts, 2,020; ratio, 28 per cent.

Full load.—Current, 16 amperes at 200 volts; true watts, 2,000; apparent watts, 3,200; ratio, 62·5 per cent.

The wattmeter employed was carefully checked, and I have every reason to accept these results.

Now, from the central station engineer's point of view, the large starting current (exceeding that at full load) is objectionable, especially with frequent stopping and starting. And then for the supply, for example, of 200 H.P. of these motors, the low power-factor of 60 per cent., or even less, will mean running a generating set *twice* the size that would be needed were the motors driven by direct current.

As to efficiency, a good direct-current motor could easily do 20 per cent. better than the 70 per cent. stated by the makers for both these sizes. It would be of great interest to members if Mr. Wyld could give some figures concerning the power-factor and efficiency of his own plant.

Dr. Sumpner.

Dr. W. E. SUMPNER put forward the view that while many not altogether concordant statements had been given as to the relative economy in copper of different systems of distribution, the real reason for the apparent advantage of any one system over another was to be found in the increased voltage at which it was worked. The three-wire system of direct-current distribution offered many practical advantages over a two-wire system, but its superior economy in copper was solely due to the doubling of the voltage at which the current was generated. In fact, the superiority lay with the two-wire system as far as mere cost of copper was concerned when the actual voltage was made the same at which the current was generated. And, in the same way, the alleged advantage of one polyphase-current system over another in cost of copper was due in effect to the use of a higher voltage. Board of Trade regulations might restrict them to certain voltages between certain wires, and by means of a device they might supply current from the station at a higher voltage and obtain a practical advantage, but he did not believe there was any difference

in the efficiency of systems of distribution, whether by alternating or direct current, so far as the copper was concerned, except such as arose from alterations of voltage. Dr. Sumpner.

Against the use of alternating-current systems it was to be remembered that the maximum E.M.F. was $\sqrt{2}$ times the average; and then there was the increased current due to a low power-factor. The latter disadvantage was, however, not anything like so serious as was to be gathered from Mr. Sowter's remarks. Instead of 60 per cent., a power-factor of more like 80 per cent. occurred. But the whole question of direct *v.* polyphase currents seemed to him to resolve itself into this: There were two main conditions of electric supply. In the first, where they were transmitting power from a great distance, alternating systems had not to compete with direct currents, for direct current could not be used at very high voltage. The other condition was when they were distributing at relatively low voltage in a small district. There they were not so restricted as to choice of system, but were more limited by voltage regulations, and the question of economy of copper came in. An advantage of polyphase motors for use in factories was that they could use higher voltage than is employed with direct-current motors. By that he meant that, owing to the absence in polyphase motors of exposed parts connected with the mains, a higher voltage than that used with direct-current motors was equally safe; and that taking this into account, the advantage as regards economy of copper for distribution in factories lay decidedly with polyphase systems.

Mr. H. D. WILKINSON, speaking upon the advantages of alternating currents, said that the regulation obtainable by their use was very much better than was possible with direct currents in cases where power and light had to be carried over several miles. He had found that the highest pressure that could be used economically with direct current was 500 or 600 volts, and the regulation obtainable with this pressure was very unsatisfactory in consequence of the large currents required. In a distribution of this kind there were many advantages in polyphase motors and also in polyphase distributing circuits and generating machinery. He was interested in a scheme connected with coal-mines in the Colonies. The electric coal-cutters were operated with direct current; but the exposed parts in motors at the fairly high tension necessary for perhaps two miles of workings were disadvantageous. He had found, on the other hand, that the polyphase motor was excellently adapted to coal-cutting, as was proved also by their very successful use for this purpose in the north. There was this advantage, that anything that had to be touched in starting up was merely at a low tension. The rotor circuit was a low potential part of the machine, and the high-tension stator circuit could be made mechanically absolutely free from danger, while the stator main switch could be closed in. Mr. Wilkinson.

He agreed with Dr. Sumpner that the figures given by Mr. Sowter as to small power-factor were scarcely any guide, since they referred only to very small motors. Still, the power-factor became a serious question where one had to deal with a large number of motors distributed over a wide area; and he was hoping that a simple

Mr. Wilkinson.

apparatus would yet be devised for bringing up the power-factor automatically—in the way, for example, that over-excitation of the field of rotary converters serves to check a low power-factor. He was convinced, however, of the utility of polyphase motors for driving apparatus in factories and mines.

Mr. Rosevere.

Mr. G. R. ROSEVERE said that in point of general management, alternating currents gave much less trouble than continuous currents. Instead of the commutator there were the collecting-rings, with which nothing much could go wrong. Then the internal windings of the rotor were simpler and could be made more mechanical than those of the direct-current armature. The alternating motor was made of fewer parts and was stronger, requiring less attention. The distribution of power in factories to the various tools by three-phase currents could be carried out better and more economically than with continuous currents, the advantage being more especially present in the case of large tools.

Mr. Mensing.

Mr. L. C. H. MENSING had seen many important installations, both in the United States and on the Continent, which illustrated in a striking manner the way in which the polyphase system lent itself to every kind of work, and was more readily adapted and much safer than direct currents. The polyphase motor had only reached its present state of perfection through long and costly experience. Much of the wear of the direct-current commutator was due to sparking at starting, and this was absent in polyphase motors. Referring to several important installations on the Continent which had had systems of direct-current power distribution and were now changing over to polyphase equipment, he instanced a case in Barmen where he was told that the saving effected in cost of distribution and management by this change was as much as 50 per cent. The direct-current distribution of power in the Russian Government dockyards at Odessa was being replaced by a polyphase plant.

Mr. Vaudrey

Mr. J. C. VAUDREY could not take quite the same point of view as Mr. Wyld in regard to the polyphase system. While for transmission of power over long distances, and possibly also for distribution in factories, polyphase plant might be desirable, yet as regards the cost of distributing mains in a network system such as was to be found in London, Manchester, Liverpool, or Birmingham, we had still much to learn. He would have been glad if Mr. Wyld could have given them figures on this point. His own experience went to show that the direct-current motor gave very little trouble indeed. In Birmingham they had from two to three hundred motors in connection with the electric lighting service at 200 volts, and they hardly ever heard anything about them. He denied that commutators gave any trouble in a properly made enclosed motor. Then, as to wiring, there were always three wires, if not four, in polyphase systems, as against two for direct current; and there was trouble in balancing the lighting load. He thought that the wiring and fittings were much simpler and better when direct currents were used.

Summing up, Mr. Vaudrey said that he was of opinion, not merely that the direct-current motor gave very little trouble, but that for purposes of general distribution over a restricted area there was yet a great deal to be said for the use of direct currents.

Mr. R. H. HOUSMAN considered the question of direct *v.* alternating currents to be of the greatest importance. Most of them who had had much experience in looking after a number of continuous-current motors would rather hail the opportunity of dispensing with commutators. Faults were often due to copper dust from a dry commutator. The possibility of getting rid of commutators was a great point in favour of polyphase motors; but they wanted information on other points. The efficiency of direct-current motors was pretty well known, but figures were wanting on the efficiency of various sizes of polyphase motors and how it varied at different loads. Then, as to price, how did the polyphase motor compare in cost per kilowatt with the direct-current motor? Again, with regard to the question of balancing the three circuits, would an unequally balanced lighting load combined with a motor load simply mean unequal heating in the coils, or would it derange the working of the motors? And how did the Tesla single-phase motor compare in efficiency and cost? Information was badly wanted on alternate-current motors on many such points. Mr. Housman.

Mr. A. M. TAYLOR said that in most factories the loss of power in direct-current conductors was of small account, since with even 1,000 amperes per square inch the drop was only 20 volts per quarter mile—a 5 per cent. average loss. In appraising the relative merits of systems it was a question rather of whether the installation was ultimately to be self-contained or to be supplied from some large scheme of power distribution. In the latter case it would be obviously an advantage to put down polyphase motors, for it was questionable whether it would pay to put in rotary converters afterwards. But he thought that a very good case could be made for continuous currents in factories. A vital point was the economy in power. It was this which determined in many cases whether electric plant was to be put in at all. It had to be borne in mind that all the motors in factories were not loaded up to their full capacity. He did not think the average load would be much over 50 per cent. And the question then arose, would the polyphase motor compare favourably with the direct-current motor under these circumstances? From what he had seen, it gave 70 per cent. as against 75 per cent. efficiency in, say 15 H.P. direct-current motors—five per cent. clear gain for the continuous-current motor. Another serious defect of the polyphase motor was in the matter of speed regulation. This was commonly effected by putting resistance into the rotor circuit; but to do this was almost like putting resistance into the armature circuit of a direct-current motor, and they all knew with what disastrous results as regards economy this was attended. There were also two other methods of reducing the speed, but these were not very satisfactory, and it seemed to him they must fall back on the resistance in the rotor circuit. That afforded a poor range of regulation, whereas with a continuous motor they could quite economically vary the speed over a wide range. Lastly, with reference to the power-factor he thought that this would be found to fall off with reduced load still faster than the efficiency, and so give rise to increased line losses. Mr. Taylor was therefore of opinion that both in the matter Mr. Taylor.

Mr. Taylor. of speed regulation and efficiency at small loads, the polyphase motor was not equal to the continuous motor.

(Discussion adjourned, and resumed on April 17th.)

Mr. Bate. Mr. A. H. BATE remarked that, as Dr. Sumpner had pointed out, the economy in the three-phase system was due to the high voltage employed. But this was limited by the stress on the insulation, and in Mr. Wyld's case, the 350 volts used meant about 500 volts maximum stress. In considering the cost of mains it must be remembered that when they came to be replaced the old copper was valuable, whereas old insulation was worthless. A saving in copper which brought with it any increase in cost of insulation might not prove to be an economy. Then the torque of the polyphase motor was limited, while that of the direct-current motor was in an emergency almost unlimited. Had this limit any effect on the distribution, and was it necessary in consequence to group machinery on to a large polyphase motor rather than run each machine by separate small motors? With regard to the relative weight of different motors, he had compared the weights of 10 H.P. motors of two well-known firms, and found the semi-enclosed direct-current machine to be 15 per cent. lighter than the alternating-current motor. But this might be due to a difference in rating. Some makers sold machines on the understanding that the load during a long uninterrupted run would not rise above an average of 75 per cent. of full load. He would be glad to learn how polyphase motors were usually rated.

Mr. Pearson. Mr. A. PEARSON said that, neglecting the power-factor, the three-phase system required only 75 per cent. of the copper required for continuous-current transmission; but this difference was almost neutralised in practice when account was taken of the power-factor. Then, the initial cost of polyphase generating plant was much greater. And the starting currents gave rise to more difficulty in regulation than did those of continuous motors. The commutator also of continuous-current machines was not nearly as bad as it was painted, and this was at most but a negative advantage for the polyphase motor. He thought Mr. Vaudrey's recommendation of the continuous-current motor was a very good one. In comparing the price of motors it was important, of course, to specify the speed. At slow speeds, the price was a point in favour of the direct-current motor. The direct-current system was, finally, very much simpler in wiring and in everything connected with the measuring and controlling appliances.

Mr. Blackburn. Mr. A. B. BLACKBURN said that the Electric Construction Company had been making polyphase motors and they worked satisfactorily, but it must be borne in mind that all that could be done by a polyphase motor could be done by a continuous-current one also, and much more besides. For, while the polyphase motor corresponded to an ordinary shunt motor, there was nothing to correspond with a series or compound winding. The system certainly required less copper, but there must be much more wiring. The starting current was also relatively great, and this was serious if many motors had to be started at the same time. In introducing a new motor we must be cautious in making the change. The advantage due to absence of commutator was entirely illusory,

Any good maker could ensure absolute sparklessness; while, on the other hand, it was necessary to have a very small clearance indeed in order to obtain a good power-factor. Mr. Blackburn.

Mr. HENRY LEA had, since the last meeting, had the pleasure of seeing Mr. Wyld's polyphase plant at Wednesbury, and was certainly struck with the appearance of simplicity. He thought there must be an advantage in the high-tension current being confined to the fixed coils of the motors. The three wires instead of two did not suggest any difficulty. They were simply formed into one cable and drawn through iron pipes. The question seemed to resolve itself into two points. First, did the polyphase system cost more or cost less than the continuous current; and second, what was the value of the advantage arising from absence of commutators? If with a greater cost the polyphase system was still used, some other reason than that of cost must be found for its adoption. Was it that there were no commutators? Not that Mr. Wyld had made a bugbear of commutators, but he, Mr. Lea, had never had much trouble with commutators. He had put down a number of motors for fans at the Birmingham General Hospital, including one 7½ H.P. motor; three 6 H.P. and four 5 H.P. motors. These had been running continuously night and day, week-days and Sundays, for a period of over three and a half years, except when stopped for turning up the commutators. The 7½ H.P. motor had run over three years before its commutator had required turning up, and had used up one and a half pairs of brushes. Of the four 5 H.P. motors, two had their commutators turned up three times and the others twice in the period. This showed that under good conditions the cost of new brushes and repairs to commutators was hardly worth considering. The speed of these motors could be altered over a range of from 900 to 450 revolutions per minute without the use of resistances in the armature circuits, and therefore with practically no loss of efficiency. Such regulation of motors generally was, however, not often required. Mr. Wyld had said a good deal in his paper on the subject of regulation of speed of polyphase motors, but the necessity for regulation of speed was the exception rather than the rule, so that the objections against polyphase motors on this score were not of very great importance. Mr. Lea.

Mr. W. WYLD, in replying, said: The figures given by Mr. Sowter of tests of very small single-phase motors hardly bear, I think, on the question of polyphase equipments, and as to the low efficiencies which he gives, I think, with Dr. Sumpner and the other speakers, that instead of the power-factors being only 43 to 62 per cent., that they are more like 80 per cent. for polyphase motors. It is hardly to be expected that Mr. Vaudrey, who has so large and successful continuous-current supply in his charge, *should* see eye to eye with any one advocating another system; but I am afraid that in speaking he rather turned his thoughts and remarks to the question of distributing energy over large areas, such as town supply, for he said I had entirely failed to give any data on mains distribution, which was of supreme importance in large towns, and that, as far as he could gather, the polyphase current had not been distributed in the network system such as Mr. Wyld.

Mr. Wyld. was to be found in London, Manchester, Liverpool, or Birmingham. I quite agree with Mr. Vaudrey that there is a great deal to learn in that direction, but would remind him that the paper under discussion was not on this subject. With respect to his remarks upon the polyphase plant which he had seen with so many loose wires hanging about, I must say I think it an extreme case, and that this cause of complaint was more the fault of the person who was responsible for the work, than of the system. I am pleased to hear from our chairman that he was not so much impressed by the number of wires whilst seeing over my plant, and I might add that whilst going through the shops he asked where they were. I, of course, referred him to Mr. Vaudrey. I was pleased to hear that the commutators of the continuous-current motors gave no trouble in Birmingham, and I think many engineers throughout the country will wish theirs would behave as well. Mr. Housman evidently had not found continuous-current motors to behave as well as Mr. Vaudrey had, and therefore hails the opportunity of getting rid of the commutator troubles. With respect to his enquiry as to the efficiencies of polyphase motors, the commercial efficiency of a 20 B.H.P. motor is about 91 per cent. at full load. and about 87 to 88 per cent. at half load. With respect to the variation of load on different phases, this is only due to an alteration on the lighting circuits. *i.e.*, between any of the phases and the neutral, for all the motors are connected up to the three phases, and thus are balanced. Should, however, the lighting load get very much out of balance, it does not affect the motor load at all, and the variation in voltages on the lighting circuit is not nearly so serious as is usually thought. For instance, if all the load be thrown off two of the three phases, the variation of pressure on the one left is only about 2 per cent., and this does not derange the working of the motors. In answer to the enquiry as to the prices of polyphase motors compared with those of continuous-current machines, for small motors there is a difference in favour of the polyphase, whilst for larger machines with wound rotors there is not much difference. Referring to the inquiry *re* the Monocyclic System designed by Mr. Steinmetz, of the American General Electric Company, this is scarcely a polyphase system, but an arrangement for enabling single-phase motors to start under load by the addition of a teaser winding, whereby a small current 90° apart from the main current enables the motors to act at starting as two-phase machines and start under load.

Mr. Taylor asked if the efficiency of a polyphase motor at half load would compare favourably with a continuous-current motor at half load, and seemed to think that the continuous-current motor had at least 5 per cent. better efficiency. I have particulars of some tests of several polyphase motors of various sizes, and instead of the efficiency being, as Mr. Taylor said, only 70 per cent. at half load, it works out at more like 88 per cent. for half load and 80 per cent. for quarter load; so that the average efficiency on an all-day load for a polyphase motor is distinctly higher than that of an ordinary continuous-current motor is, and is not nearly as bad as Mr. Taylor appeared to think it was. With respect to their efficiency at various

speeds, however, though the power-factor remains constant the efficiency is not as high at slow speed, but is not nearly as low as Mr. Taylor made it out to be; and it must be remembered that these variable speed motors, such as are used on cranes, etc., are not run for very long periods at slow speeds, so the loss is not as serious as is usually thought. Mr. Wyld.

In answer to the enquiry how I obtained the figure of 42 per cent. for the load-factor on the generating station, I took it in the ordinary way, *i.e.*, $\frac{\text{units output} \times 100}{\text{maximum load} \times \text{hours}}$.

In answer to Mr. Bate's inquiry as to whether the polyphase motor would stand overloading for a short time, it would stand it as well, if not better, than a continuous-current machine up to at least 50 per cent. It is not necessary to group machines together on to one motor for this reason, as the polyphase motor can be direct-coupled to an individual machine if desired. With respect to the weight of polyphase motors, it must have been an exceptional case that Mr. Bate had taken, for as a rule the polyphase motor is lighter than the continuous. Mr. Pearson referred to the induction in the three cores; this is usually got over by twisting the three cores round each other. The voltage is not appreciably affected with the starting of a motor, particularly one with a wound rotor and a starting resistance. Only one ammeter is necessary to measure the current taken by a motor, and not two as suggested by Mr. Pearson. In reply to Mr. Vaudrey's query, I don't think there is very much difference in the makes of polyphase motors, not nearly as much as in continuous-current machines. I am sorry to hear from Mr. Blackburn that a polyphase plant is being taken out, but am glad he told us that it was not necessarily the fault of the system. With respect to the disadvantage of wiring for polyphase motors, I have not experienced any difficulty. I was glad to hear our chairman speak as he did on the simplicity of the wiring; he certainly appeared to expect to see a lot of wires when he came round the works. In answer to the first point which he raised as to the cost of the polyphase system, I might say that when we were putting down our plant we had tenders and quotations in for a continuous-current plant from several of the best makers, and the polyphase was below the others in cost. This, of course, may not be the general rule, but in this particular instance it was considerably lower on the whole than the continuous-current system. With reference to Mr. Lea's remarks about variable speed motors, I may say that all of this class that we use are on cranes, and I think with Mr. Lea that, as a rule, they are of secondary importance in a factory.

ORIGINAL COMMUNICATIONS.

NOTE ON DUPLEXING OF CABLES.

By H. H. KINGSFORD, Member.

It is, I believe, customary when duplexing a long cable to use artificial line somewhat but not much shorter than the cable proper, but to the best of my knowledge the method which I am about to describe, and which requires but a comparatively small amount of artificial line, was not employed until it occurred to me some time ago; it has now been in use for many months.

A fall in the insulation of some underground cables between hut and office threatened to interfere with duplex working, and it became necessary, therefore, to devise some plan which would obviate the difficulty. The method which

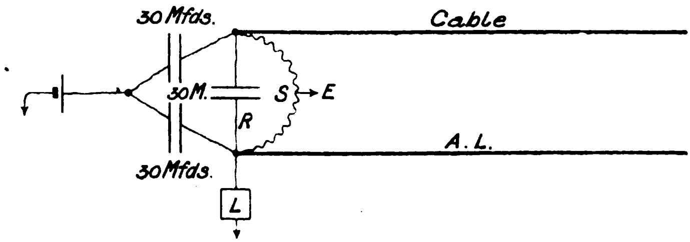

FIG. 1.

I adopted was simplicity itself, and proved entirely satisfactory. It consisted merely in placing a resistance earthed at about its middle point between the commencement of the cable and that of the artificial line. The length of the cable was eight hundred knots, the artificial line which was normally employed having a resistance of 7,435 ohms and a capacity of 232 microfarads. When a resistance of 2,000 ohms, earthed at about its middle, was placed between the points above named, we found that the last two boxes of the artificial line, representing 2,304 ohms and 72 microfarads, could be dispensed with without making any perceptible difference to the balance, the signals at the distant end being as easy to read as they were before the earthed shunt was applied. Using a shunt of lower resistance we were, as might be expected, able still further to shorten the artificial line, but, with the same battery, signals were of course very small when the resistance of the earthed shunt was very low.

As an experiment we worked duplex through a K.R. of $2 \cdot 06 \times 10^6$. The insulation resistance of the underground cable at the sending end varied somewhat, the average being probably about 2,400 ohms, which was balanced by a leak "L" of corresponding resistance. The shunt "S" had a resistance of 200 ohms, earthed at about its middle point, and the K.R. of the artificial line was 37,400. The signals were readable, but they were not good; I have no doubt, however, that we could have made them perfectly safe, despite the variable resistance of the underground cable, had we devoted more time to the experiment. The connections are shown in Fig. 1.

When using the earthed shunt method at one end of the cable only, the resistance of that shunt may sometimes be very low if the balance at the distant end be perfect and if the distant recorder be very sensitive, as under those conditions both stations could, assuming the electrical condition

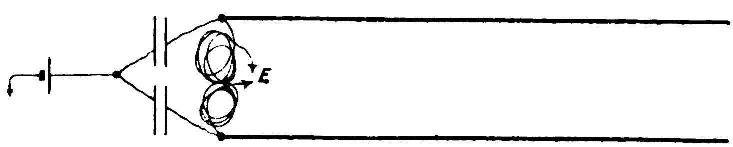

FIG. 2.

of the cable to be safe, use a large E.M.F. for signalling, and the distant station could obtain good signals with the minimum amount of current.

This method of course facilitates obtaining and maintaining duplex balance as it makes the recorder somewhat sluggish, which is often an advantage, and renders any change in the cable due to fault, etc., less apparent.

We made also experiments with a double-wound recorder coil, connections as in Fig. 2, with which arrangement the greater portion of the received current is utilised in the recorder; but a condenser or its equivalent is, of course, necessary in the recorder circuit when the cable is subject to strong and variable currents from earth, atmosphere, or fault. Many different arrangements of resistances or condensers, or of both, will doubtless suggest themselves, but so far the plan, Fig. 1, has always given entire satisfaction. The advantages of the "Earthed Shunt" method appear to be, as already stated, economy in artificial line, and facility for obtaining and maintaining duplex balance.

THE CAPACITIES OF POLYPHASE CABLES.

By ALEXANDER RUSSELL, M.A., Member.

In order to calculate the currents due to capacity that will flow in the various conductors of a polyphase cable, it is necessary that certain measurements be made, not only of the capacity of each conductor, but also of the mutual capacities between it and the other conductors which form the cable. As these conductors are generally arranged symmetrically, two, or at the most three, measurements of the capacities are all that need be made, as all the others can then be deduced by simple formulæ. The object of the following paper is to prove these formulæ, and to indicate how they can be used in certain important practical cases to calculate the capacity currents in the mains. Professor C. E. Guye has pointed out[1] that concentric mains are unsuitable for polyphase work at very high pressures owing to their high capacity, and also because the condenser currents are not symmetrically distributed between the three conductors.

Electricians, when they first attack the problem, are puzzled by the apparent complexity introduced by the fact that the quantity of electricity on any one conductor enclosed in the sheathing of the cable depends, not only on its own potential, but also on the potentials of the neighbouring conductors, and hence it is not allowable to assume that the charge on any one conductor divided by its potential is a constant. Professor Guye,[2] however, has shown that in the important case when the various arms of the system are symmetrically loaded, we are justified in making this assumption, and he has given an easy graphical method of taking the capacity currents into account.

A discussion of the general problem of the charges on conductors when neighbouring conductors are at given potentials, has been given by Clerk Maxwell,[3] and Oliver Heaviside has given formulæ for calculating the capacities and coefficients of electrostatic induction for overhead electric wires.[4] Maxwell defines the capacity of a con-

[1] *L'Éclairage Électrique*, Jan. 20, 1900; *Science Abstracts*, vol. iii., p. 437.

[2] "Les Courants de Capacité dans les Lignes Polyphasées Symétriques," *L'Éclairage Électrique*, June 16, 1900; *Science Abstracts*, vol. iii., p. 723.

[3] *Electricity and Magnetism*, vol. i., § 87.

[4] *Journ. Soc. Tel. Eng.*, 1880, vol. ix., p. 115.

ductor as its charge when its own potential is unity and that of all the other conductors is zero. He shows that the charge q_1 on any conductor whose potential is v_1 may be written in the form

$$q_1 = K_{1\cdot 1}\, v_1 + K_{1\cdot 2}\, v_2 + K_{1\cdot 3}\, v_3 + \ldots + K_{1\cdot n}\, v_n \ldots$$

where $K_{1\cdot 1}$ is the capacity of the given conductor according to the above definition; v_2, v_3, . . . the potentials of neighbouring conductors, and $K_{1\cdot 2}$, $K_{1\cdot 3}$, . . . are constant coefficients which are called coefficients of induction. Any one of them, as $K_{1\cdot n}$, denotes the charge on the given conductor when the n^{th} conductor is raised to potential unity, all the other potentials being zero. The mathematical calculation of these coefficients is difficult, and in the case where the section of these conductors is not a geometrical figure, as in the "clover leaf" three-phase cable made by the British Insulated Wire Company, a rough approximation is obviously all that is possible. We have not attempted these calculations in this paper.

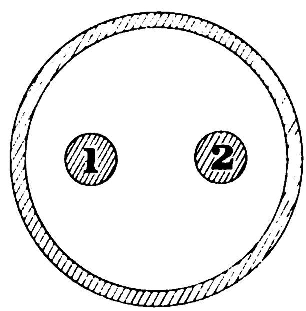

FIG. 1.

Maxwell states that the dimensions of capacity and coefficients of induction are the same as those of a line, so that the magnitude of each of them can be represented by a straight line, whose length is independent of the system of units employed. All the coefficients of induction of a conductor as, for example, $K_{1\cdot 2}$, $K_{1\cdot 3}$ . . . are negative, but the numerical value of the sum of them all can never be greater than $K_{1\cdot 1}$ the capacity of the conductor itself, which is of course always positive.

Single-Phase Cable.

Let the two conductors (Fig. 1) be embedded in insulating material. Let $K_{1\cdot 1}$ be the capacity per mile of No. 1 conductor, let v_1 be its potential at any instant, and let $K_{1\cdot 2}$ be the coefficient of mutual electrostatic induction per mile between the two conductors. We will assume that v_1 is practically constant throughout the whole length of the cable at any instant. In other words, we assume that the

ohmic drop is negligible. Then if q_1 be the quantity of electricity in a mile of the conductor—

$$q_1 = K_{1\cdot1}\, v_1 + K_{1\cdot2}\, v_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where v_2 is the instantaneous value of the potential of No. 2 conductor.

Similarly—

$$q_2 = K_{2\cdot2}\, v_1 + K_{2\cdot1}\, v_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

But from symmetry—

$$K_{2\cdot2} = K_{1\cdot1} \text{ and } K_{1\cdot2} = K_{2\cdot1}$$

Hence—

$$q_2 = K_{1\cdot1}\, v_2 + K_{1\cdot2}\, v_1$$

Now if the fault resistance of No. 1 main, *i.e.*, the resistance of all the leakage paths of No. 1 main to earth, be f_1 and the fault resistance of No. 2 main be f_2, then since the sum of the leakage currents from No. 1 to earth must equal the leakage current to No. 2 from earth, therefore—

$$\frac{v_1}{f_1} + \frac{v_2}{f_2} = 0$$

Let v equal the potential difference between the mains, and let F be the insulation resistance to earth of the two in parallel, then—

$$v = v_1 - v_2 \quad \text{and } F = \frac{f_1 f_2}{f_1 + f_2}$$

$$\therefore \quad \frac{v_1}{f_1} = -\frac{v_2}{f_2} = \frac{v}{f_1 + f_2}$$

$$\therefore \quad v_1 = \frac{F}{f_2} v$$

And—

$$v_2 = -\frac{F}{f_1} v$$

These equations show that v_1 and v_2 are similar curves, and that their phase-difference is 180 degrees.

If i_1 denote the condenser current flowing into No. 1 conductor, and i_2 be the condenser current flowing into No. 2 conductor, then—

$$i_1 = \frac{dq_1}{dt}$$

$$= K_{1\cdot 1}\frac{dv_1}{dt} + K_{1\cdot 2}\frac{dv_2}{dt}$$

$$= \left(K_{1\cdot 1} - \frac{f_2}{f_1}K_{1\cdot 2}\right)\frac{dv_1}{dt}$$

Similarly—

$$i_2 = \left(K_{1\cdot 1} - \frac{f_1}{f_2}K_{1\cdot 2}\right)\frac{dv_2}{dt}$$

Hence, in calculating the capacity currents of the cable shown in Fig. 1, we can suppose that it has no capacity, and that the conductors are connected to the sheathing

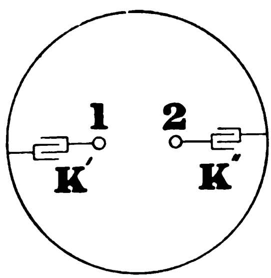

FIG. 2.

through two condensers (Fig. 2) whose capacities K′ and K″ are given by the equations—

$$K' = K_{1\cdot 1} - \frac{f_2}{f_1}K_{1\cdot 2}$$

$$K'' = K_{1\cdot 1} - \frac{f_1}{f_2}K_{1\cdot 2}$$

If I_1 and I_2 are the effective values of i_1 and i_2, then—

$$\frac{I_1}{I_2} = \frac{K' f_1}{K'' f_2}$$

If v be the potential difference between the conductors 1 and 2, it has been customary hitherto to calculate the condenser current i by the formula—

$$i = K\frac{dv}{dt}$$

where K is the capacity between the two conductors. Now by formulæ (1) and (2) it is easy to show that—

$$i_1 - i_2 = \left(K_{1\cdot1} - K_{1\cdot2}\right)\frac{dv}{dt}$$

and we will show later on that—

$$K = \frac{1}{2}\left(K_{1\cdot1} - K_{1\cdot2}\right)$$

Hence—

$$i_1 - i_2 = 2i$$

Since v_1 and v_2 are similar curves that differ in phase by 180 degrees, it follows that i_1 and i_2 are similar curves which also differ in phase by 180 degrees, hence—

$$I_1 + I_2 = 2\,I,$$

where I is the effective value of i.

Hence—

$$I_1 = 2\frac{K' f_1}{K' f_1 + K'' f_2}\,I$$

And—

$$I_2 = 2\frac{K'' f_2}{K' f_1 + K'' f_2}\,I$$

If I_1 is greater than I, I_2 is smaller, and *vice versâ*.

In the case when No. 2 conductor is earthed—

$$i_1 = K_{1\cdot1}\frac{dv_1}{dt}$$

$$i_2 = K_{1\cdot2}\frac{dv_1}{dt}$$

$$i = \frac{1}{2}\left(K_{1\cdot1} - K_{1\cdot2}\right)\frac{dv_1}{dt}$$

$$\therefore\ I_1 = \frac{2\,K_{1\cdot1}}{K_{1\cdot1} - K_{1\cdot2}}\,I \quad \text{and } I_2 = \frac{-\,2\,K_{1\cdot2}}{K_{1\cdot1} - K_{1\cdot2}}\,I$$

Example.—In the lead-covered low-tension twin cable of the British Insulated Wire Co. described at the end of the paper, $K_{1\cdot1}$ is 0·53 mfd. per mile, and $K_{1\cdot2}$ is − 0·16. Hence if No. 2 conductor be earthed—

$$I_1 = \frac{1\cdot06}{0\cdot69}\,I = 1\cdot54\,I$$

And—

$$I_2 \qquad = 0\cdot46\,I$$

When the system is balanced—

$$f_1 = f_2 \text{ and } K' = K'' = 2K = K_{1\cdot1} - K_{1\cdot2}$$

In this case—

$$I_1 = I_2 = I$$

Determination of $K_{1\cdot1}$ and $K_{1\cdot2}$ for single-phase cables.

(1) Measure the capacity K_1 between one conductor, 1, and the other in parallel with the sheathing, 2, S, then by definition—

$$K_{1\cdot1} = K_1$$

(2) Measure the capacity K_2 between the two conductors in parallel, 1, 2 and the sheathing, S. From equations (1) and (2)—

$$q_1 + q_2 = 2\,(K_{1\cdot1} + K_{1\cdot2})\,v$$

Hence—

$$K_{1\cdot1} + K_{1\cdot2} = \frac{1}{2}\,K_2$$

$$\therefore \qquad K_{1\cdot2} = -\left(K_1 - \frac{1}{2}\,K_2\right)$$

A knowledge of $K_{1\cdot1}$ and $K_{1\cdot2}$ enables us to write down the capacity K between the two conductors. Since the two conductors are surrounded by the lead sheathing, and hence are completely screened, we must have—

$$q_1 + q_2 = 0.$$

Hence from equations (1) and (2)—

$$(K_{1\cdot1} + K_{1\cdot2})\,(v_1 + v_2) = 0$$

$$\therefore \quad v_1 = -v_2$$

$$\therefore \quad q_1 = (K_{1\cdot1} - K_{1\cdot2})\,v_1$$

$$= \frac{1}{2}\,(K_{1\cdot1} - K_{1\cdot2})\,(v_1 - v_2)$$

$$\therefore \quad K = \frac{1}{2}\,(K_{1\cdot1} - K_{1\cdot2})$$

It also follows that—

$$4\,K + K_2 = 4\,K_1.$$

This equation can be used to check our measurements.

Three-phase Cables.

We will suppose that the three conductors are sym-

metrically embedded in the dielectric. Then if we neglect the resistance of the conductors and use the same notation as before—

$$
\begin{aligned}
q_1 &= K_{1\cdot1}\, v_1 + K_{1\cdot2}\, v_2 + K_{1\cdot3}\, v_3 \\
q_2 &= K_{2\cdot1}\, v_1 + K_{2\cdot2}\, v_2 + K_{2\cdot3}\, v_3 \\
q_3 &= K_{3\cdot1}\, v_1 + K_{3\cdot2}\, v_2 + K_{3\cdot3}\, v_3
\end{aligned}
$$

From symmetry $K_{1\cdot1} = K_{2\cdot2} = K_{3\cdot3}$ and $K_{1\cdot3} = K_{3\cdot1}$ etc. When the potentials to earth are balanced, which is the important case in practice, then—

$$v_1 + v_2 + v_3 = 0$$

Therefore—

$$
\begin{aligned}
q_1 &= (K_{1\cdot1} - K_{1\cdot2})\, v_1 \\
q_2 &= (K_{1\cdot1} - K_{1\cdot2})\, v_2 \\
q_3 &= (K_{1\cdot1} - K_{1\cdot2})\, v_3
\end{aligned}
$$

Hence in calculating the capacity currents in practice,

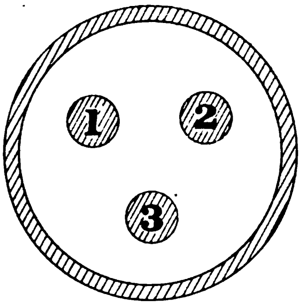

FIG. 3.

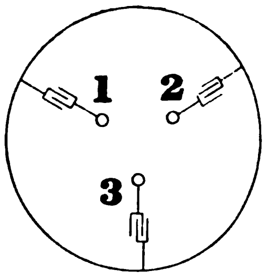

FIG. 4.

we can suppose that the conductors have no capacity and are joined to the sheathing (Fig. 4) by three condensers, each of capacity 2 K, where—

$$2\,K = K_{1\cdot1} - K_{1\cdot2}$$

This theorem is due to Professor Guye.

The exact calculation of the capacity currents when the potential differences between the conductors and earth are not balanced is difficult, but a minimum limit can be fixed to the sum of the three condenser currents.

Let i_1, i_2 and i_3 be the three condenser currents, then—

$$i_1 - i_2 = \left(K_{1\cdot 1} - K_{1\cdot 2}\right)\frac{d}{dt}(v_1 - v_2)$$
$$= 2\,K\frac{dv}{dt} = a_1$$
$$i_2 - i_3 = 2\,K\frac{dv''}{dt} = a_2$$
$$i_3 - i_1 = 2\,K\frac{dv'''}{dt} = a_3$$

where v', v'' and v''' are the mesh voltages of the three-phaser. In general when the P.D.'s to earth of the three conductors are out of balance, the waves of P.D. v', v'' and v''' between the three terminals of the machine are all of

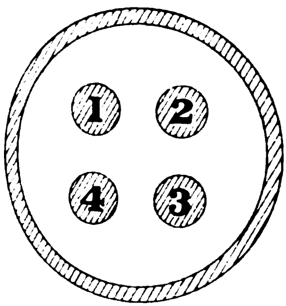

FIG. 5.

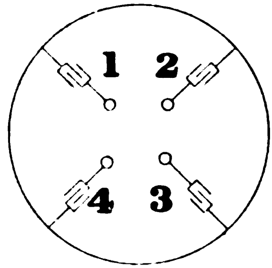

FIG. 6.

different shapes. Hence, if A_1, A_2 and A_3 be the effective values of a_1, a_2 and a_3, we can write—

$$A_1 = \alpha V'\,2\,Kf,\quad A_2 = \beta V''\,2\,Kf,\quad \text{and } A_3 = \gamma V''\,2\,Kf,$$

where the value of α, β or γ cannot be less than 2π and f is the frequency. It can be proved that $I_1 + I_2 + I_3$ is never less than $\frac{1}{2}(A_1 + A_2 + A_3)$, hence $I_1 + I_2 + I_3$ is never less than $2\pi(V' + V'' + V''')\,Kf$. K is the capacity between any two of the three conductors.

To find $K_{1\cdot 1}$ and $K_{1\cdot 2}$ for a three-phase cable.

(1) Measure the capacity K_1 between one of the mains, 1, and the others in parallel with the sheathing, 2, 3, S, then—

$$K_{1\cdot 1} = K_1$$

(2) Measure the capacity K_2 between 1, 2, and 3, S, then—

$$K_{1\cdot1} + K_{1\cdot2} = \frac{1}{2} K_2$$

$$\therefore \quad K_{1\cdot2} = -\left(K_1 - \frac{1}{2} K_2\right)$$

Knowing the values of $K_{1\cdot1}$ and $K_{1\cdot2}$, we are able to write down all the various combinations of capacities between the conductors and the sheathing.

The capacity between 1 and 2, 3, S $= K_{1\cdot1}$

" " " 1, 2 and 3, S $= 2\,(K_{1\cdot1} + K_{1\cdot2})$

" " " 1, 2, 3 and S $= 3\,(K_{1\cdot1} + 2K_{1\cdot2})$

" " " 1 and 2 $= \frac{1}{2}\,(K_{1\cdot1} - K_{1\cdot2})$

" " " 1 and 2, 3 $= \frac{2}{3}\,(K_{1\cdot1} - K_{1\cdot2})$

Makers, therefore, when describing cables should give the values of $K_{1\cdot1}$ or $K_{1\cdot2}$.

Two-phase cables with four separate conductors.

Using the same notation as before, we have—

$$q_1 = K_{1\cdot1} v_1 + K_{1\cdot2} v_2 + K_{1\cdot3} v_3 + K_{1\cdot4} v_4,$$

and three similar equations.

From symmetry—

$$K_{1\cdot1} = K_{2\cdot2} = \text{etc.}$$
$$K_{1\cdot2} = K_{1\cdot4} = K_{2\cdot3} \text{ etc.}$$
$$K_{1\cdot3} = K_{2\cdot4}$$
$$\therefore\ q_1 = K_{1\cdot1} v_1 + K_{1\cdot3} v_3 + K_{1\cdot2}(v_2 + v_4)$$

Now if the system is balanced—

$$v_1 + v_3 = 0$$
$$v_2 + v_4 = 0$$

Hence—

$$i_1 = \frac{dq_1}{dt}$$
$$= \left(K_{1\cdot1} - K_{1\cdot3}\right)\frac{dv_1}{dt}$$
$$i_2 = \left(K_{1\cdot1} - K_{1\cdot3}\right)\frac{dv_2}{dt}$$
$$i_3 = \left(K_{1\cdot1} - K_{1\cdot3}\right)\frac{dv_3}{dt}$$
$$i_4 = \left(K_{1\cdot1} - K_{1\cdot3}\right)\frac{dv_4}{dt}$$

Hence, when we neglect the resistance of the conductors, the effect of capacity can be shown by imagining that the conductors have no capacity, but are joined by four condensers, each of capacity $K_{1 \cdot 1} - K_{1 \cdot 3}$ connected star-wise between the conductors (Fig. 6). This theorem is also due to Professor Guye.

If the P.D.'s to earth are not balanced, then—

$$i_1 - i_2 = \left(K_{1 \cdot 1} - K_{1 \cdot 2}\right)\frac{dv'}{dt} - \left(K_{1 \cdot 1} - K_{1 \cdot 3}\right)\frac{dv'''}{dt},$$

where $v' = v_1 - v_2$ and $v''' = v_3 - v_4$.

Hence, as in the case of three-phase mains, we can find an inferior limit to the sum of the four effective condenser currents. The graphical solution of the problem is in this case difficult, as we need to have recourse to solid geometry.

To determine $K_{1 \cdot 1}$ and $K_{1 \cdot 3}$—

(1) Measure the capacity K_1 between 1 and 2, 3, 4, S, then $K_{1 \cdot 1} = K_1$.

(2) Measure the capacity K_2 between 1, 3 and 2, 4, S,

$$\text{then } K_{1 \cdot 1} + K_{1 \cdot 3} = \frac{1}{2} K_2,$$

$$\therefore \quad K_{1 \cdot 3} = -\left(K_1 - \frac{1}{2} K_2\right)$$

The capacity K_3 between 1 and 3 when 2, 4, S are to earth is $\frac{1}{2}\left(K_{1 \cdot 1} - K_{1 \cdot 3}\right)$ hence—

$$4 K_3 + K_2 = 4 K_1$$

This equation can be used for checking purposes.

Many similar relations between the capacities of various combinations of the conductors can easily be written down.

Two-phase cable in which the common return conductor is a cylinder surrounding the other two.

In Fig. 7, (1) and (4) are what are ordinarily called the two outside conductors, and (23) or (x) is their common return. The copper used in (x) is 1·414 times the copper

used in either (1) or (4). When the system is balanced, the P.D. between (1) and (x) is equal to the P.D. between (4) and (x), but differs in phase from it by 90 degrees. The P.D. between (1) and (4) is 1·414 times the P.D. between (1) and (x), or between (4) and (x), and its phase difference from either of them is 135 degrees.

Let v_1, v_x and v_4 be the potentials from earth of (1) (x) and (4) respectively, then as before—

$$q_1 = K_{1\cdot 1}\, v_1 + K_{1\cdot x}\, v_x + K_{1\cdot 4}\, v_4$$
$$q_x = K_{x\cdot 1}\, v_1 + K_{x\cdot x}\, v_x + K_{x\cdot 4}\, v_4$$
$$q_4 = K_{4\cdot 1}\, v_1 + K_{4\cdot x}\, v_x + K_{4\cdot 4}\, v_4$$

From symmetry $K_{1\cdot 1} = K_{4\cdot 4}$ and $K_{1\cdot x} = K_{x\cdot 1}$, etc.

Since one conductor surrounds the other two, we must

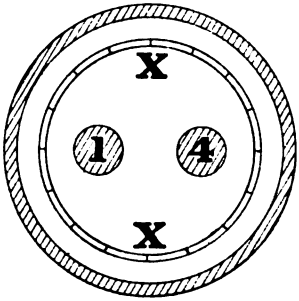

FIG. 7.

have at every instant $q_1 + q_x + q_4 = 0$. Since also v_1, v_x and v_4 can have any values,

$$\therefore\ K_{1\cdot 1} + K_{x\cdot 1} + K_{4\cdot 1} = 0$$
$$K_{x\cdot x} + 2\, K_{1\cdot x} = 0$$
$$\therefore\ q_1 = K_{1\cdot 1}\,(v_1 - v_x) + K_{1\cdot 4}\,(v_4 - v_x)$$
$$\therefore\ i_1 = K_{1\cdot 1}\frac{dv'}{dt} + K_{1\cdot 4}\frac{dv''}{dt},$$

where $v' = v_1 - v_x$ and $v'' = v_4 - v_x$.

If v' and v'' are similar waves differing from one another in phase by ninety degrees, then the curves represented by $\frac{dv}{dt}$ and $\frac{dv}{dt}$ will also differ in phase by ninety degrees, and if in addition the effective values of v' and v'' are equal,

then the effective value I of the condenser current in either (1) or (4) is given by—

$$I_1^2 = \left(K_{1.1}^2 + K_{1.4}^2\right)\left\{\text{mean value of } \left(\frac{dv'}{dt}\right)^2\right\}$$

$$\therefore\ I_1 = a\,V_{1.x}\left(K_{1.1}^2 + K_{1.4}^2\right)^{\frac{1}{2}} f,$$

where a is a constant depending on the shape of the wave, $V_{1.x}$ is the P.D. between (1) and (x), and f is the frequency. The minimum value of a is 2π.

If the condenser current in (x) is i_x, then—

$$i_x = \cdot K_{1.x}\left(\frac{dv'}{dt} + \frac{dv''}{dt}\right)$$

$$\begin{aligned}\therefore\ I_x &= -\,a\,V_{1.x}\,\sqrt{2}\,K_{1.x} f\\ &= a\,V_{1.x}\sqrt{2}\,(K_{1.1} + K_{1.4}) f\\ &= a\,V_{1.4}\,(K_{1.1} + K_{1.4}) f.\end{aligned}$$

It easily follows from these formulæ that I_x is always less than $\sqrt{2}\,I_1$.

Example. In the twin concentric cable described at the end of the paper, $K_{1.1} = 0{\cdot}233$ microfarad per mile, and $K_{1.4} = -0{\cdot}048$ mfd. per mile. Hence for a cable a mile long $I_1 = a\,V_{1.4} f \times 0{\cdot}168$, and

$$I_x = a\,V_{1.x} f \times 0{\cdot}262 = a\,V_{1.4} f \times 0{\cdot}185.$$

As the values of the capacities and coefficients of mutual electrostatic induction are apparently not well known to electricians, the following data which were given to me by my old pupil, Mr. F. E. Mackee, of the British Insulated Wire Company, will prove useful. The cables experimented on were chosen so as to illustrate the formulæ given in this paper, and I am deeply indebted to Mr. Mackee for the trouble he has taken in testing them. I have also to thank the British Insulated Wire Company for permission to publish his experimental results.

Lead-covered low tension twin cable. B. I. W. Co.

Working pressure in volts = 200.
Section of conductor = 0·1 square inch = 0·65 sq. cm.
Min. distance between the two conductors = 0·23 cm.
Min. distance between either conductor and the sheathing = 0·23 cm.
Insulating material: Impregnated paper.
Mean Specific Inductive Capacity = 2·8.

The capacity per mile between one conductor and the other conductor in parallel with the sheathing ($K_{1\cdot 1}$) is 0·53 mfd., and the capacity between the two conductors in parallel and the sheathing is 0·74 mfd.

Hence—

$$K_{1\cdot 1} = 0{\cdot}53$$
$$2\,(K_{1\cdot 1} + K_{1\cdot 2}) = 0{\cdot}74$$
$$\therefore\quad K_{1\cdot 2} = -\,0{\cdot}16$$

The capacity between the two conductors—

$$= \frac{1}{2}\left(K_{1\cdot 1} - K_{1\cdot 2}\right)$$
$$= 0{\cdot}345$$
$$= 0{\cdot}34 \text{ (by measurement).}$$

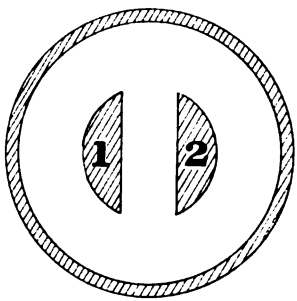

FIG. 8.

The capacity of the theoretical condenser for balanced working—

$$= K_{1\cdot 1} - K_{1\cdot 2}$$
$$= 0{\cdot}69 \text{ mfd. per mile.}$$

Three-phase "clover leaf" extra high tension cable supplied to the Manchester Corporation. B. I. W. Co.

Working pressure in volts between the conductors = 6500.

Working pressure between any conductor and the sheathing = 3750.

Section of a conductor = 0·15 sq. inches = 0·97 sq. cm.

Min. distance between cond. and sheathing, Min. distance between any two conductors } = 0·86 cm.

Insulating material: Specially prepared paper.

The capacity per mile between two of the conductors in parallel and the other in parallel with the sheathing, *i.e.* between 1, 2 and 3, S is 0·436 mfd., and between the three conductors and the sheathing it is 0·488 mfd.

Hence—

$$\left.\begin{aligned} 2\,(K_{1\cdot1} + K_{1\cdot2}) &= 0{\cdot}436 \\ \text{And}\quad 3\,(K_{1\cdot1} + 2\,K_{1\cdot2}) &= 0{\cdot}488 \end{aligned}\right\}$$

$$\begin{aligned} \therefore \quad K_{1\cdot1} &= 0{\cdot}273 \\ \text{And} \quad K_{1\cdot2} &= -\,0{\cdot}0553 \end{aligned}$$

These quantities $K_{1\cdot1}$ and $K_{1\cdot2}$ determine all the other capacities.

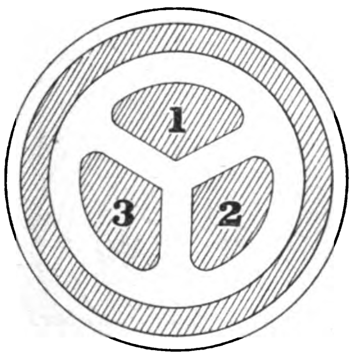

FIG. 9.

For example—

$$\left.\begin{aligned} \text{The capacity between 1 and 2, 3, S} = K_{1\cdot1} &= 0{\cdot}273 \\ \text{By measurement} &= 0{\cdot}268 \end{aligned}\right\}$$

$$\left.\begin{aligned} \text{The capacity between 1 and 2} = \frac{1}{2}\left(K_{1\cdot1} - K_{1\cdot2}\right) &= 0{\cdot}164 \\ \text{By measurement} &= 0{\cdot}165 \end{aligned}\right\}$$

$$\left.\begin{aligned} \text{The capacity between 1 and 2, 3} = \frac{2}{3}\left(K_{1\cdot1} - K_{1\cdot2}\right) &= 0{\cdot}219 \\ \text{By measurement} &= 0{\cdot}217 \end{aligned}\right\}$$

The capacity per mile of the theoretical condenser required in calculations—

$$\begin{aligned} &= K_{1\cdot1} - K_{1\cdot2} \\ &= 0{\cdot}328 \end{aligned}$$

The pressure across the terminals of this condenser is 3750 volts, hence the minimum value of the condenser current in each conductor when the potentials to earth are

balanced, is 0·386 ampere per mile of cable when the frequency is 50.

Lead-covered four-core pilot cable. B. I. W. Co.

Working pressure in volts = 100
Section of conductor = 0·007 sq. inch.
= 0·045 sq. cm.
Min. dist. bet. adj. cond. = 0·18 cm.
" " " cond. and sheathing = 0·15 cm.
Insulating material: Impregnated paper.
Mean S.I.C. = 2·8

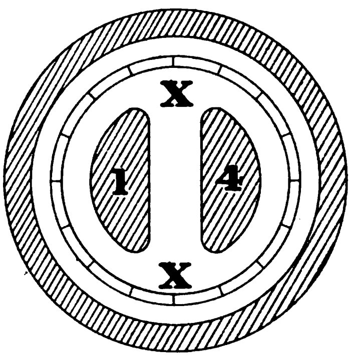

FIG. 10.

By experiment—

The capacity between 1 and 2, 3, 4, S = 0·234
" " 1, 3 and 2, 4, S = 0·454

Hence—

$$\left.\begin{aligned} K_{1\cdot1} &= 0{\cdot}234 \\ \text{And}\quad 2(K_{1\cdot1} + K_{1\cdot3}) &= 0{\cdot}454 \end{aligned}\right\}$$

$$\therefore\quad K_{1\cdot3} = -0{\cdot}007$$

$$\text{The capacity between (1) and (3)} = \frac{1}{2}\left(K_{1\cdot1} - K_{1\cdot3}\right)$$

$$\left.\begin{aligned} &= 0{\cdot}120 \\ \text{By measurement} &= 0{\cdot}120 \end{aligned}\right\}$$

$$\left.\begin{array}{r}\text{The capacity of the theoretical condensers} \\ \text{for balanced working}\end{array}\right\} = K_{1\cdot1} - K_{1\cdot3}$$

$$= 0{\cdot}241$$

Twin concentric cable for two-phase currents. B. I. W. Co.

Working pressure between inner conductors—
= 2700 volts.

" " " either inner and outer ring—
= 1900 volts.

Section of inner conductor = 0·025 sq. inch.
= 0·161 sq. cm.

Section of outer ring conductor = 1·414 × 0·161 sq. cm.
= 0·228 sq. cm.

Min. dist. between inner cond. = 0·56 cm.

" " " inner and outer = 0·63 cm.

The capacity between 1 and 4, x = 0·233

The capacity between 1, 4 and x = 0·370

Hence—

$$K_{1 \cdot 1} = 0 \cdot 233$$
$$2\,(K_{1 \cdot 1} + K_{1 \cdot 4}) = 0 \cdot 370$$
$$\therefore\ K_{1 \cdot 4} = -\,0 \cdot 048$$

The capacity between 1 and 4 $= \frac{1}{2}\left(K_{1 \cdot 1} - K_{1 \cdot 4}\right)$

$$\left.\begin{array}{r} = 0 \cdot 141 \\ \text{By measurement } = 0 \cdot 149 \end{array}\right\}$$

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JOURNAL

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The Three Hundred and Sixty-fifth Ordinary General Meeting of the Institution was held at the Society of Arts, John Street, Adelphi, on Thursday evening, May 9th, 1901—Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on May 2nd, 1901, were read and confirmed.

The names of new candidates for election into the Institution were announced, and it was ordered that the list should be suspended in the Library.

The following transfers were announced as having been approved by the Council :—

From the class of Associates to that of Members :—

George Sutton.

From the class of Associates to that of Associate-Members :—

William P. Durtnall. | Oswin Hansom.

Messrs. S. Joyce and A. Russell were appointed scrutineers of the ballot for the election of new members.

A donation to the Building Fund was announced as having been received since the last meeting from Mr. C. F. Wilkins, to whom the thanks of the meeting were duly accorded.

The PRESIDENT : I have to announce that the area of the Glasgow Local Section has been defined. It is an area

enclosed in a circle of fifty miles' radius from some point in Glasgow, excluding that part of the circle which lies east of 3·30 meridian of longitude, which leaves Edinburgh out of the circle.

STORAGE BATTERIES IN ELECTRIC POWER STATIONS, CONTROLLED BY REVERSIBLE BOOSTERS.

By J. S. HIGHFIELD, Member.

The use of storage batteries in direct current central stations has now become general, but there seems to be a great divergence of practice among station engineers in the matter of the proportion that the battery bears to the steam plant. A table in the Appendix gives the proportion of battery capacity to the steam plant capacity in many direct current stations, the figures having been obtained through the courtesy of the engineers of the various towns in supplying the figures. There seems to be no good reason for this great diversity of practice, and this paper is written with the object of putting before engineers what seem to be the chief points in considering the designing of batteries for the work they are called on to do in central stations, and to describe subsidiary apparatus which may be found of use and convenience in operating batteries. It is convenient to divide stations into three varieties, namely, (1) Lighting and general supply stations; (2) Traction stations; and (3) Combined stations for supplying to the general town network, and to a tramway system.

In laying down a station for a general town supply, where the load factor may not be more than 12 per cent., and where the difference of the magnitude of the load in winter and summer is great, it has been customary to instal a battery having a capacity, reckoned at a three-hour rate of discharge, of but a small proportion of the whole station plant. This battery is usually very useful in the first years of the supply, but as the load increases from year to year, the battery is worked altogether beyond its capacity, and so falls into a bad state of repair, and into disuse; and additions to plant do not very often include corresponding additions to the battery. This ill-treatment of the battery is very

frequent in stations where the battery works the night shift, as there is a great temptation to delay increasing the capacity of the battery or the hours of working the plant till the last possible moment, and the battery under these circumstances is frequently run down ; needless to say it is very soon irreparably damaged. It seems hardly necessary at this date to insist on the absolute necessity of using storage batteries with the greatest care, of giving them at least as much skilled attention as the rest of the station plant. If an armature becomes grounded, or a commutator damaged, the repairs are not a very serious matter, but neglect of a battery, too heavy charging or discharging, insufficient charging, and over-discharging, damage to some extent every plate in the battery, and consistent treatment of this sort will rapidly reduce the storage capacity, and the efficiency of working at the same time.

In an ordinary lighting and general supply station, the battery is nearly always divided into two parts—one, the main battery, consisting of a number of cells arrived at by dividing the pressure in volts maintained at the bus bars by 2·5, the usual voltage at which charge is assumed to be complete; the remaining part of the battery consists of such a number of cells as to make the whole number in the battery equal to the figure obtained by dividing the bus bar volts by 1·85, the lowest pressure to which it is usual to allow each cell to fall on discharge. This second, or regulating section of the battery, is connected to switches which enable more or less of the regulating cells to be connected to the bus bars ; the arrangements differ somewhat in different stations, but substantially this is universal practice. For charging, a special dynamo is run at the necessary pressure, or boosters are used to raise the bus bar pressure to that desired.

These devices of heavy regulating switches, boosters, and their connections, are exceedingly costly, and very difficult to operate in practice; moreover the risk of short circuits between the bars connecting to the regulating switches is somewhat great, and in most stations the battery switch gear is more complicated and more costly than any other part of the switching equipment. The arrangements for charging the battery are two : one is to disconnect the battery entirely from the working bus bars, and to connect

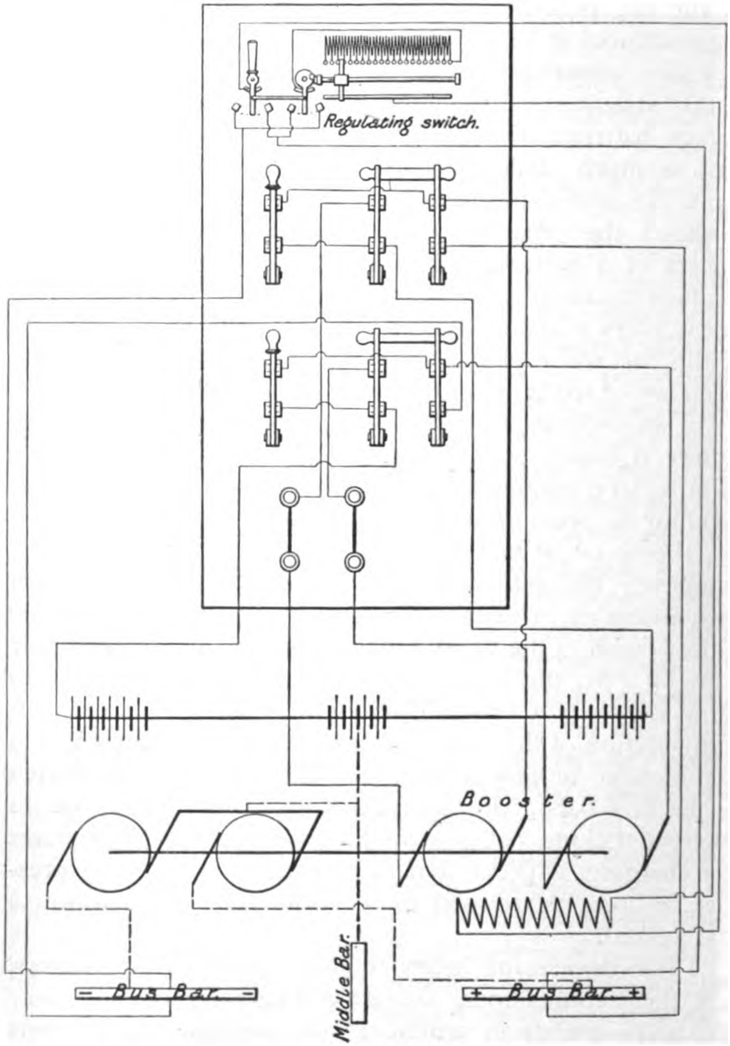


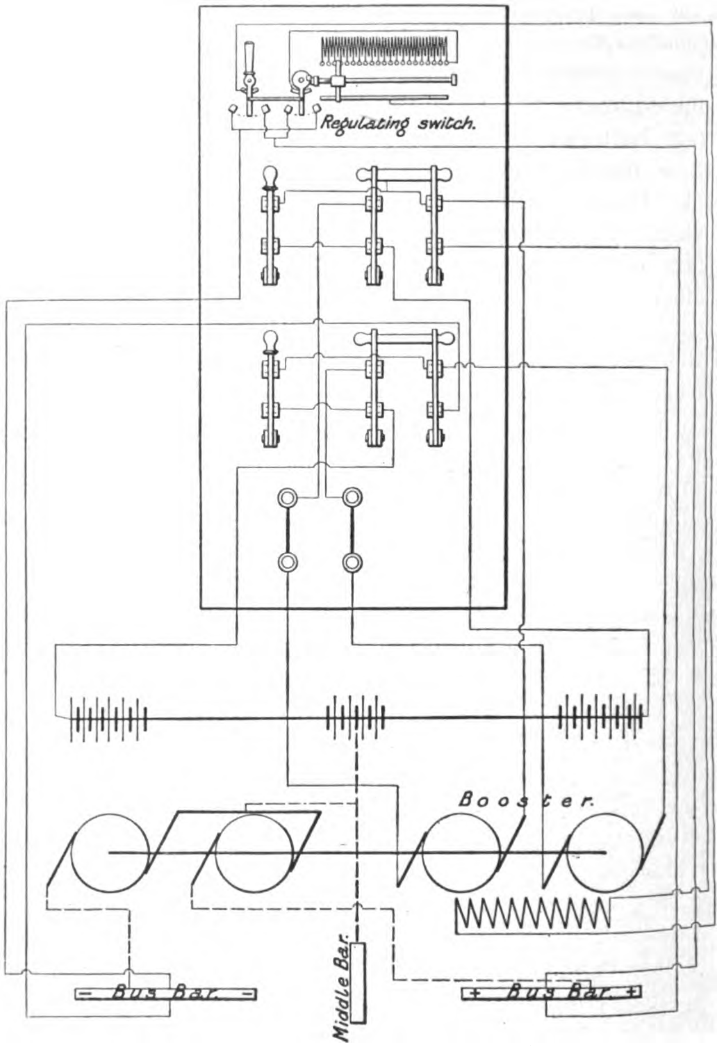
FIG. 1.—Arrangement of Variable Pressure Lighting Booster.

it to bars at a higher pressure, cutting out the regulating cells as they become charged; the other is to connect the cells to the charging bars, and to connect a less number of cells to the supply bars. In this case the charging current is greater in the end cells than in the remainder of the battery; in either case it is quite impossible to properly charge the regulating cells, and it is nearly always found that these, excepting possibly the last two or three, which are rarely used, depreciate at a far greater rate than the other cells in the battery.

After trying the regulating cell system, I decided to eliminate entirely this source of trouble and expense, and the arrangement I have used for the past two years is to regulate entirely by means of a variable-pressure booster, so designed that by varying the field strength the pressure can be varied from zero to a maximum in either direction. The booster has a double-wound armature working in one field, each half of the battery is connected in series with one of the armature windings, and the field is varied by a 30-point rheostat and a reversing switch interlocked therewith in such a way as to vary the volts given by each armature from zero to fifty, each step of the resistance serving to effect a variation of rather less than two volts. The booster is fitted with carbon brushes worked at very low current density, and no trouble is experienced when the current is large and the field strength small. The battery supplies a three-wire system, the middle point of the battery being connected to the neutral bus bar; a very good type of balancer is also used, so that the out-of-balance current dealt with by the battery is small. One half of the battery may be charged by disconnecting the other half entirely from the bus bars, and charging through the balancer.

The arrangement of electrical connections is shown diagrammatically in Fig. 1. The switch gear required to connect or disconnect the booster and the battery is exceedingly simple, and of course the whole of the necessary regulating is done by varying the amount and direction of the boost as desired.

The battery is always connected to the bus bars, and one of the most convenient purposes it serves is to act by means of the booster as the controller of the station pressure, which is regulated solely by the switch handle, which regu-



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The battery is always connected to the bus bars, and one of the most convenient purposes it serves is to act by means of the booster as the controller of the station pressure, which is regulated solely by the switch handle, which regu-

lates the strength of the booster field, and hence varies the amount of boost.

The arrangement here described was the first one I designed. It has proved an immense improvement on the regulating cell system, but has the objection that a sudden variation in the load causes a variation in the pressure. It is very desirable to make the regulation of the station as automatic as possible, provided that no very delicate gear is used, and the automatic booster to be shortly described would certainly be an improvement on the one above mentioned. I am at present arranging to use an automatic booster in connection with a three-wire lighting battery. The arrangement of the switch gear shown on Fig. 1 is not the best. I am now arranging to use an interlocked gear designed to prevent all possibility of accident by a careless operator.

The method of operation is as follows :—

Should the pressure rise by reason of a diminishing load, the boost is varied so as to cause the battery to discharge less, or to charge more. Should the pressure fall, the booster is regulated so as to work in the opposite sense. If the speed of the generators is arranged for full load at the correct pressure, by regulating the station pressure by the booster and battery, the generators will always, in an almost automatic way, be kept at full load, provided always that the battery is of proper capacity.

The battery, of course, also serves as a store of energy, which is used to drive the entire load when it is so small as not to be sufficient for a single generator. There are, therefore, three purposes which the battery serves to fill.

1. It serves, with suitable means of regulation, as a controller of the station pressure.
2. It serves as a store, so that the running generators may be always fully loaded, and also it may carry the peak of the load, and so serve to improve the load on the steam-raising plant.
3. It serves as a store of energy which may be drawn on at times when the load is within its capacity.

In stations of small size up to, say, 1,000 kw., the battery is of immense use in steadying the pressure, especially when

a few rather large motors are connected to the mains; in large stations where units of large size are used, this is not a matter of so much importance.

The battery is also a great source of security in the case of partial short circuits on the mains; it will easily burn out a fault, which might damage the generators, and with very little fall in the pressure. I have had experience of several cases where the battery has burnt a bad main's fault clear, the first news of such an accident coming from the outside gang.

To fully fulfil the above purposes, it is necessary to properly proportion the battery to the work which it has to do in relation to the work done directly by the running plant, and it is necessary to take into account the capital cost of batteries in order to decide to what extent it is advisable for financial reasons to instal them in a central station. It is convenient to work out the cost of the battery per kilowatt of discharge at various rates. Fig. 2 gives the cost per kilowatt of storage batteries, including the booster and switch gear complete and ready for work, but excluding the cost of the battery house. The table applies to batteries for 480 to 500-volt circuits, consisting of 240 cells, which is the best number to use for 460 to 480-volt lighting circuits when the booster method of control is adopted. The gear is all designed to work at the one-hour rate—if designed for the three-hour rate a reduction of about 10 per cent. would be made. The cost of steam and electrical plant—excluding buildings—may vary from £25 to £50 per kilowatt capacity. Taking £35 as the usual figure for small stations, it will be seen from the curves (Fig. 2) that at about a three-hour rate of discharge the battery costs per kilowatt of possible output the same amount as the running plant, and as the size of the battery increases the cost per kilowatt somewhat decreases. At a one-hour rate of discharge the cost of the battery is less than the cost of plant of a similar output. The "peak" of a lighting station does not usually last for more than two or three hours in a town where late-closing shops make up a large proportion of the load. The proportion of the maximum load constituting the peak varies from one-quarter to one-sixth, that is to say, if the peak is defined as an amount of load constituting one-fourth to one-sixth of the maximum load, this peak does not remain on for

more than three hours, it is usually less. If the battery is to take the whole of the peak it must, therefore, be designed to have a capacity, reckoned at the rate of discharge which will run it down in three hours, of at least one-fourth to one-sixth of the maximum load on the station. In a new station of moderate size the battery might be made to bear a larger proportion to the plant installed than this,

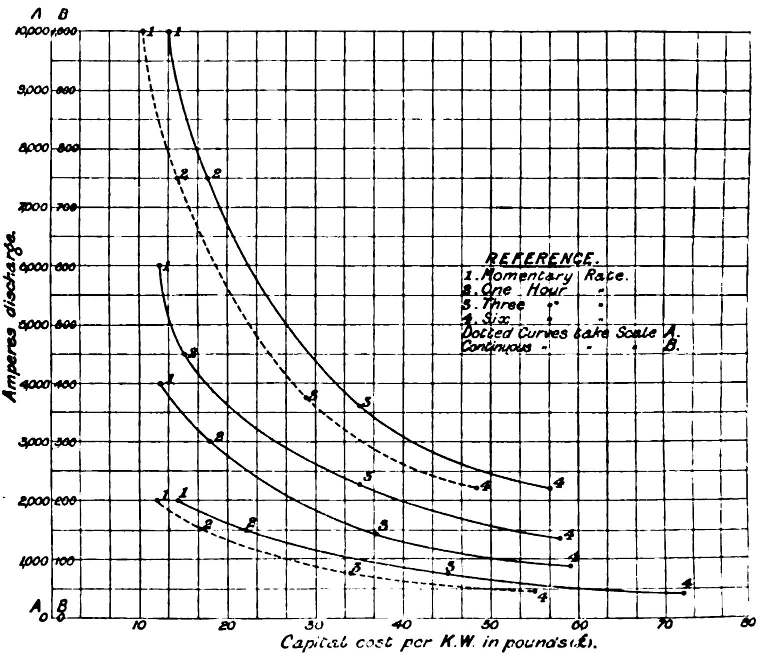

FIG. 2.—Cost of Batteries with Reversible Booster and Switchgear erected complete.

The batteries consist of 240 to 250 cells, and the capacity is taken as 30 per cent. less than the full rated capacity when the battery is new, so that at the end of a period, depending on the work and treatment of the battery, the actual capacity will be up to its rated value.

as large batteries and their controlling gear are somewhat less costly than small ones, and are also less trouble, owing to the fact that they are usually more solidly constructed.

A battery of sufficient size to carry the peak for three hours will be able to serve the three purposes set forth above in a very complete way, and the loss of energy in

the battery will generally be amply compensated for by the increased economy due to working the engines at full load and to the improvement of the steam-raising plant load factor. The load factor of the steam-raising plant is usually very poor, the fuel wasted in raising steam and keeping hot long ranges of pipes constitutes a considerable portion of the fuel usefully consumed. It seems impossible to lay down general rules as to the working of boilers in electric works; the only thing to be said, a fact readily conceded, is that the greater the regularity of working of the steam-raising and distributing plant the greater will be the economy. In works of 1,000 kw. capacity or less it will be generally most economical to drive the load from midnight to 6 a.m. from the battery—in summer time the load may be often carried in this way for a longer period—and a battery designed to carry the peak for three hours will generally be sufficient to do this. The boiler fires would be banked during these hours, and one shift of men saved.

In larger stations, however, the coal thus used would be nearly as much as if an engine were running all night, and probably in stations above 1,000 kw., and certainly in stations above 2,000 kw., it would be more economical to drive the load from the running plant, charging the battery to keep the engine at full load. Then on the load rising in the morning the battery would be discharged until the demand increased sufficiently to load up a second engine, again charging the battery.

Small stations supplying residential towns must be considered on a somewhat different basis from large stations supplying manufacturing towns in respect of the use of batteries as of other matters. In a small station the battery can supply economically a far greater proportion of the yearly output than in a large station.

In stations of less capacity than 500 kw. the usual practice has been to put down at least two sizes of engines; it might be better practice to put down two or three engines of equal size and a battery of sufficient capacity to give the output of one engine for three hours. It is not difficult to predict the extent of the load in residential towns of small size, and if it be assumed that in, say, five years time, 800 kw. will be required, a station laid down with two 100-kw. generators, and a battery capable of giving about

100 kw. for three hours, will make a far more economical station than one in which one or two smaller units are put down to start with. As the load on such a station increased, engines of similar size to those first installed should be put down, the plant being thus maintained of uniform pattern.

In stations of larger size a greater number of units would be installed, and in order to load up the running engines to their full capacity it would usually be necessary to instal a battery equal in capacity to the output of one engine for three hours, so that in general the ratio of the battery capacity to the total capacity of the plant will be less in large stations than small ones in inverse proportion to the number of units.

In determining the best size of battery for an existing station, the engineer might consider into what number of units he would divide the plant if he could design and erect an entirely new station. Most engineers in such a case would probably decide to make all the units of similar capacity; the battery should then be of such size as to take the whole output of one unit for a period of three hours, or alternatively two units, of say one-half of the capacity of the standard unit, might be installed, and a battery equal in capacity to one of these units. The nature of the all-night load must be considered in this connection, however, and the size of the smallest unit and of the battery should largely be determined by the amount of the load from midnight to 6 a.m.

In the case of a station with a large street-lighting load it is not difficult to ensure that the engines are always nearly fully loaded, but even in such a case a large battery will also enable the steam-raising plant to be worked in a more uniform way, a matter as important for economy as the uniform working of the engines.

To consider a special case, a plant of 1,000 kw. will, with a load having a factor of 10 per cent., turn out per annum 870,000 units. If by the use of a battery giving 250 kw. for three hours, which, as before explained, is in most cases capable of dealing with the peak, running plant of 750 kw. capacity could do the work, and turn out the same number of units, the plant load factor would be raised from 10 per cent. to 13·4 per cent., an increase which would certainly result in greater economy in working; but

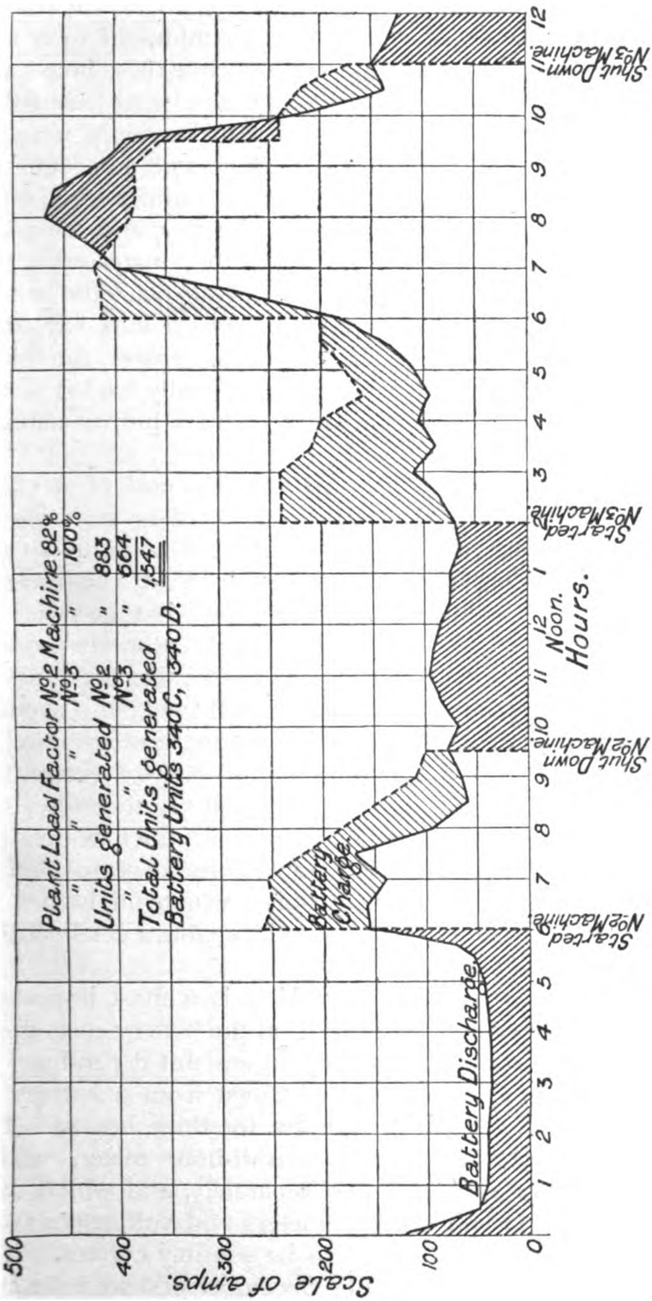

FIG. 3.—Lighting Load Diagram. Generator and Battery.

such a battery would be in nearly every case capable of carrying the whole of the load from midnight to 6 a.m. The plant could then be shut down during these hours and one shift of men saved, the running hours being lessened to this extent, the plant load factor would be raised from 10 per cent., where no battery was used, to 17·8 per cent. In most towns also this battery would, in summer time, serve to carry the load during a part of the day, and the plant load factor would be thereby still further increased. The above factor applies to the whole plant over the whole year, but since the plant would be divided into, say, four units of 250 kw. each (one unit being spare) the plant actually working could be kept always fully loaded if the battery were charged and discharged in a proper manner to attain that end.

The question of the relation between cost of working and load factor will be further considered in referring to combined stations, but reference may here be made to the fact that a lighting station deals with a load which varies through a wide range during every day, but it varies in an easily predetermined manner. With properly-proportioned, subdivided plant it is easy to ensure that the running engines always work at or near their full load; the average load on the plant considered as a whole, however, simply depends on the outside load, as will, to a great extent, the load on the boilers. In a lighting station, therefore, the battery should be designed to equalise as much as possible the boiler working. A battery sufficiently large to obviate raising steam, even in a single boiler which might not be required for more than an hour, will enable a considerable saving to be made in fuel.

The efficiency of battery working is a most important factor, since every unit supplied from the battery costs more than the units supplied direct by an amount depending on the efficiency. I have results obtained from a battery of 240 cells capable of giving 100 kw. for three hours. The units were metered through a watt-hour meter, which recorded charge and discharge separately, and which was checked by the switchboard ammeters and voltmeters from time to time, and was found to be sensibly correct. The units of charge from July 1st to December 31st were 62,560, and of discharge, 46,390 for the same period, corresponding

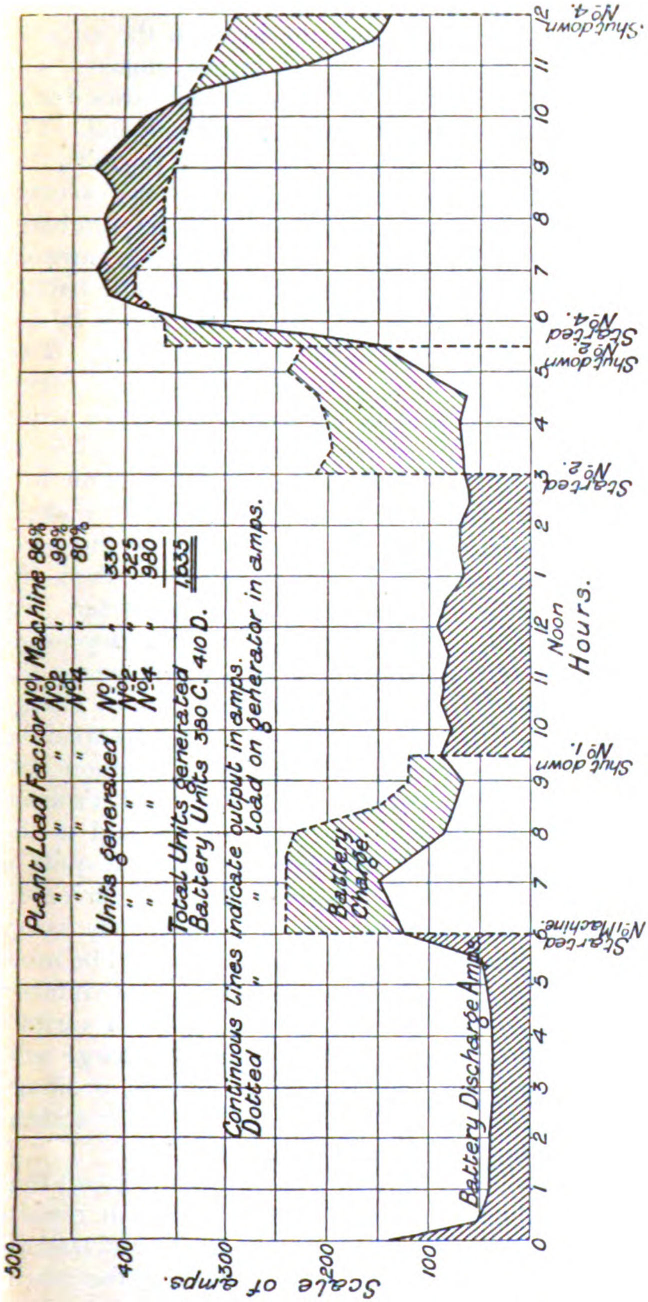

FIG. 4.—Lighting Load Diagram. Generator and Battery.

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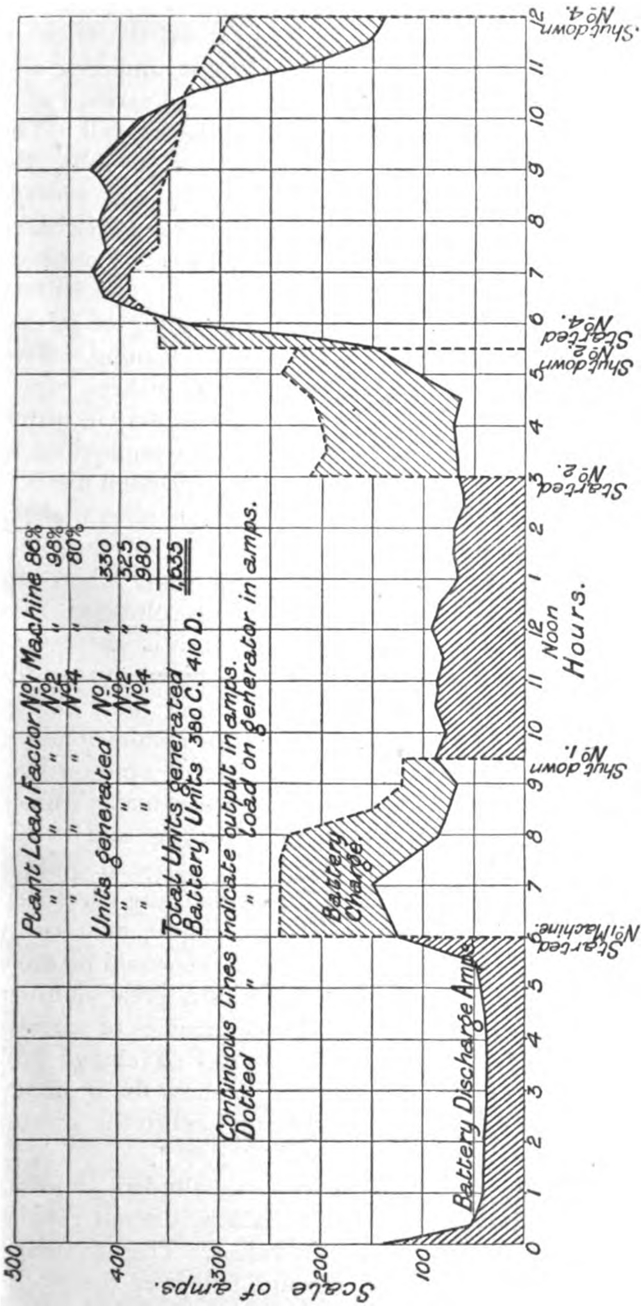

FIG. 4.—Lighting Load Diagram. Generator and Battery.

to an energy efficiency of 74 per cent. The battery is charged at varying rates to suit the load on the engines. The charging current starts at 170 to 200 amperes, and varies from time to time as the outside load varies, but it never exceeds 70 amperes when the cells are full. The maximum charging pressure per cell is 2.41 volts, the minimum discharging pressure 1.9 volts; the average charge per 24 hours is 341 units, the average discharge 253 units; the maximum discharging current is 200 amperes. Additional figures are given in the Appendix. The battery has cost for repairs a small amount, consisting of labour in filling up the cells with water and in cleaning. Two faulty positive sections were replaced by the makers, otherwise no work has been done in keeping the battery in order.

The usual directions of the makers are impossible to carry out in practice, and I find the most convenient method of keeping note of the condition of the cells is to make a weekly test all round of the specific gravity of the electrolyte, being careful to take the readings only when the cells are fully charged by the switchboard voltmeter. By comparing the results with those last taken, it is easy to see if the proper amount of charge has been given during the week; if the specific gravity has fallen, rather more charge is given to bring it right up again. From the results obtained of battery working at various times, I am of opinion that charging with a constant current at the battery maker's usual figure is not so conducive to efficient working and to the long life of the cells as finishing up the charge at quite a small current. On the other hand, the charging current at the commencement, when the cells are empty, may safely be much greater than the maker's figure. It would be most interesting to have accurate figures over a great number of charges and discharges, giving the efficiencies of various methods of working and at various rates of charge and discharge. The curves in Figs. 3 and 4 show the ordinary work done by the battery on the lighting load in the station of which I have charge.

There is one point to which I have not alluded, and that is, the immense convenience that a battery is when repairs have to be done to steam pipes or valves. The advantage of being able to shut down entirely and still keep the mains alive is so great that for this reason alone a battery in a

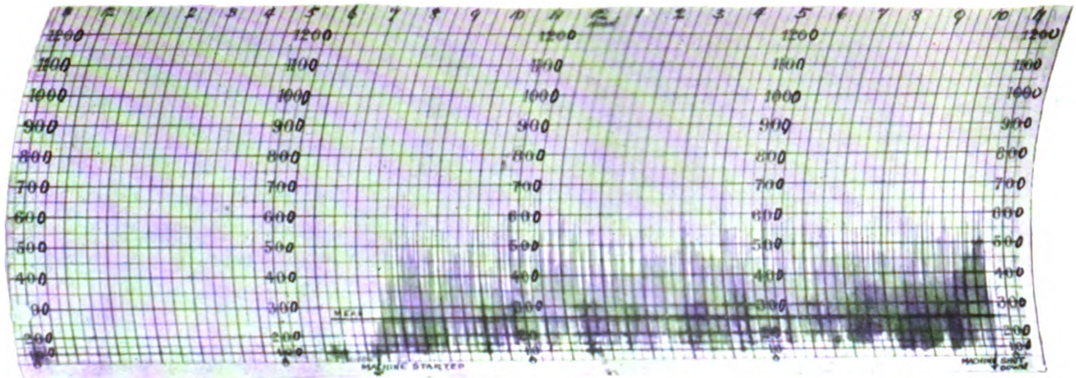

FIG. 5.—Recorder Curves for Traction Load worked with Battery and Reversible Booster.

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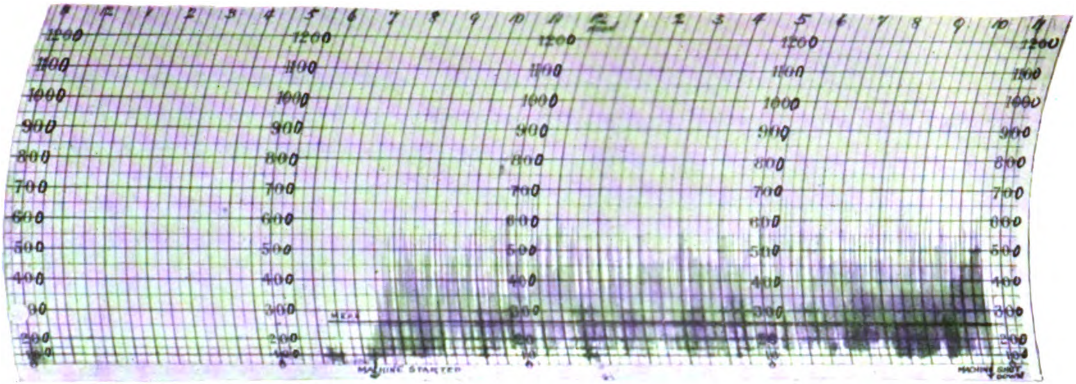


FIG. 5.—Recorder Curves for Traction Load worked with Battery and Reversible Booster.

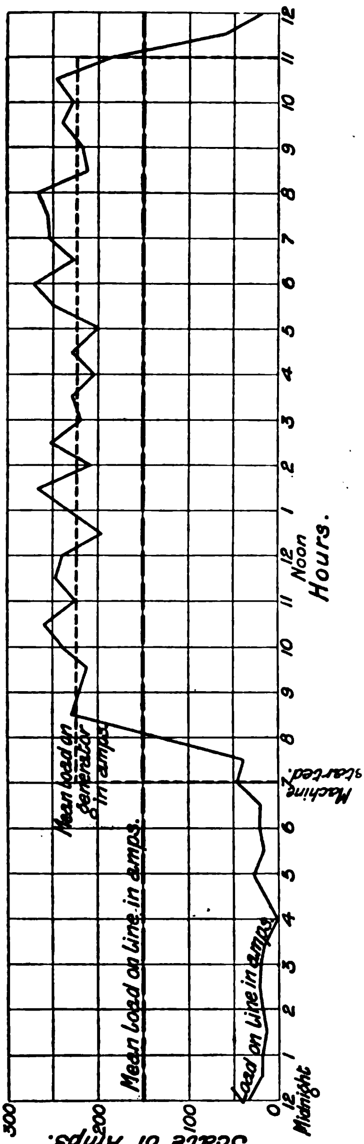


FIG. 6.—Traction Load Diagram. Generator and Battery.

central station is almost a necessity, at any rate, where a motor load exists. In such a case a shut down even for a few hours on Sunday is almost impossible, and on a week-day cannot be tolerated.

Apart from this use of batteries in the power station, there may arise occasions when the battery may be used in a substation at one or more important feeding points. About 15 per cent. of the copper put down in feeders is only required for a few hours each day for perhaps one month in the year, from the middle of December to the middle of January. This copper can be saved by using a battery in a substation, provided of course that a site can be found at not too great a cost. In addition to the saving in feeders, the economical area of distribution can be extended, and the pressure can be maintained more nearly constant. It is not possible to lay down general rules for the use of batteries in this way, but I now have a case where it is necessary to give supply at a point about three miles from the station. The extent of the supply will be about 100 kw. There is an excellent site for a substation about two and a half miles from the station, and a battery at this point works out at a less first cost than a boosted direct feeder, or a high-tension transmission scheme.

Batteries in Traction Stations.

In power stations supplying energy to work tramways and railways, the character of the load is entirely different from that of a lighting load. The output varies but little according to the time of the year, or from day to day. There are peaks during which the output and the maximum load are greater than at other times, but not nearly to so great an extent as in lighting work. The load, however, varies very rapidly and through very wide limits, the variations becoming less as the number of cars or trains increases. In the case of a road operating 50 to 100 cars, the maximum loads are usually about three times the mean load. With 100 to 200 cars, the maximum loads are usually less than twice the mean load. Fig. 5 shows the load variations for a road operating 25 to 30 cars; Fig. 6 shows the variations of the mean load at any time during the day, this curve being plotted by taking the output

in units every half-hour, and from the readings working out the load. In each figure the horizontal line shows the average load, during the hours of running the plant necessary to turn out the metered units. It is evident from the curves that a generator of 200 kw. can easily give the output if a battery be used to discharge on the peaks. For such a load the battery may be used at the one-hour rate of discharge normally, and on occasions at even a greater rate.

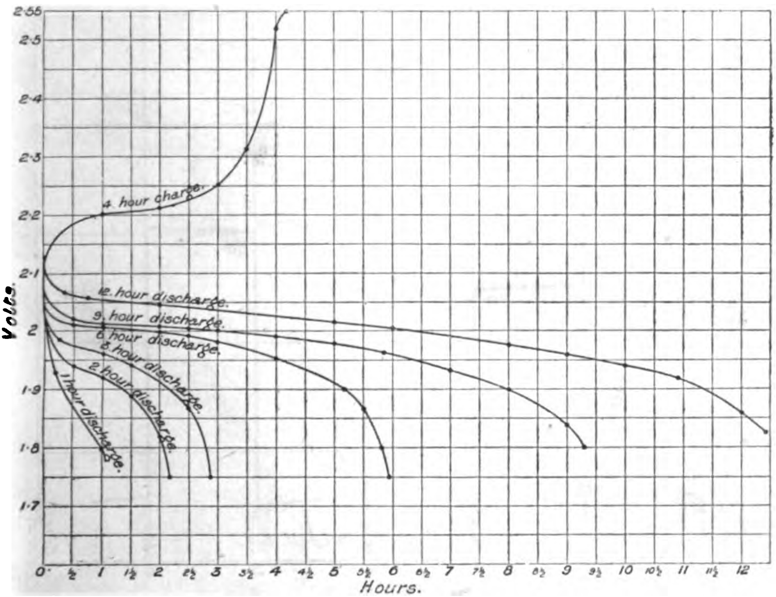


FIG. 7.—Curves showing Rise of Voltage on Charge, and Fall of Voltage on Discharge at Different Rates.

Such occasions might be when the road is very heavy through a snowfall or like reason, or when cars get bunched during holiday traffic. In the case of a traction load, therefore, the capital cost of the battery may be taken at the one-hour rate, that is, about £15 to £18 per kw. This is considerably less than the cost of the running plant.

For the load shown in Fig. 5 over 24 hours, the load-factor is 23 per cent. Such a load cannot be very economical, since the steam plant would be, on the average, very lightly loaded.

The plant load-factors for a lighting station and a traction station differ in one respect—in a lighting station, by using

units of several sizes, the engines may be run nearly at their full load always, but the load on the boiler plant will vary considerably; in a traction station, on the other hand, the boilers will supply, during about 16 hours, about the same amount of steam per hour. The engines must, however, be large enough to take the maximum load, and therefore work at only a small part of their full capacity.

If a battery be used in parallel with the steam plant on

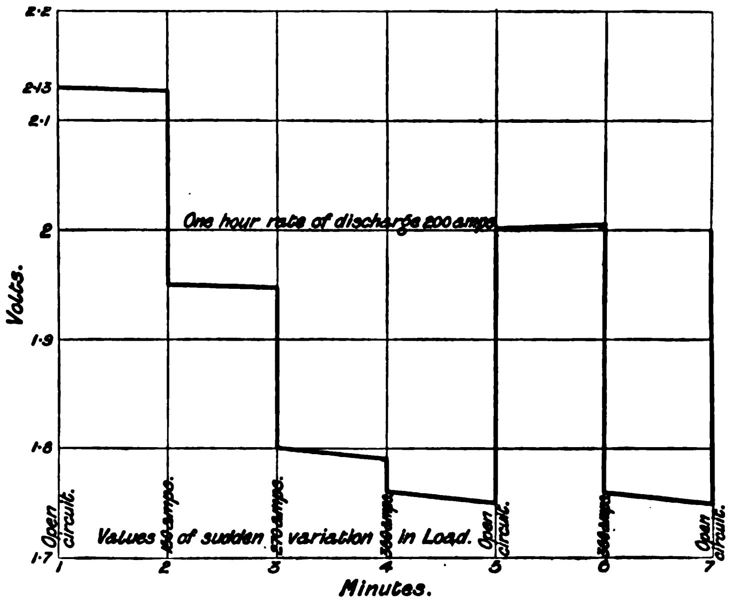


FIG. 8.—Variation in Volts of One Cell with Sudden Variation in the Load.

the load shown in Fig. 5, it will take up some portion of the peaks; but the conditions of battery discharge and charge must be such that the variations in the battery pressure must be small, which would necessitate working the battery at a much slower rate than the one-hour rate allowed for above. The ideal arrangement would be to run the generator at constant load—making the constant load as nearly the full load of the generator as possible, to work the necessary number of hours, say, 16 daily, to turn out the required number of units—and to allow the battery to take charge of all peaks, and to charge when the load is small, and to work the entire service for the remainder of the day.

It is here necessary to consider the nature of the battery as a reservoir of energy. Fig. 7 shows the well-known rise of voltage on charge and fall of voltage on discharge at various rates. Fig. 8 shows the fall in voltage due to throwing on the load in sudden steps, the fall in the latter case being due to the ohmic resistance of the cell, and possibly, to a less extent, to polarisation.

In a battery working in parallel with a shunt-wound generator at such a speed as to give about the mean output, so that the battery neither gained nor lost very much, the number of cells should be determined by the formula, No. of cells $= \frac{\text{line volts}}{2 \cdot 08}$. I have found that, when in the best condition for working in this way, a battery capable of giving 450 amperes for one hour, will discharge 200 amperes with a fall of pressure of 25 volts, and will charge 200 amperes with a rise of pressure of 25 volts, these limits being the greatest permissible on a 500-volt circuit.

With compound-wound generators the pressure rises with the load, so that the battery working in parallel with the generator will do very little work.

In working a battery in simple parallel with shunt-wound generators, it is impossible to charge the battery during working hours, and at the same time have it available to discharge on any peaks; this is a great drawback, and necessitates running longer hours to complete the charge.

The only way to work a battery on a tramway or other variable load to keep the generator output constant, to fully charge during working hours, and to discharge up to its momentary rate, is to use some device to compensate for the variation of the battery pressure. For this purpose I have used a booster of somewhat special design, the booster armature being always in series with the battery. This machine is run throughout the time the generators are working, and sometimes when the battery alone is working the line. The essential connections are shown diagrammatically in Fig. 9, and the machine itself in Fig. 10, this shows the booster driven by a motor, it might, however, be driven from the main engine. The booster *B* (Figs. 9 and 10) has laminated field magnets, excited by a fine wire coil *C* (the exciter coil), consisting of such a number of turns of such resistance that the pressure given by the armature when run

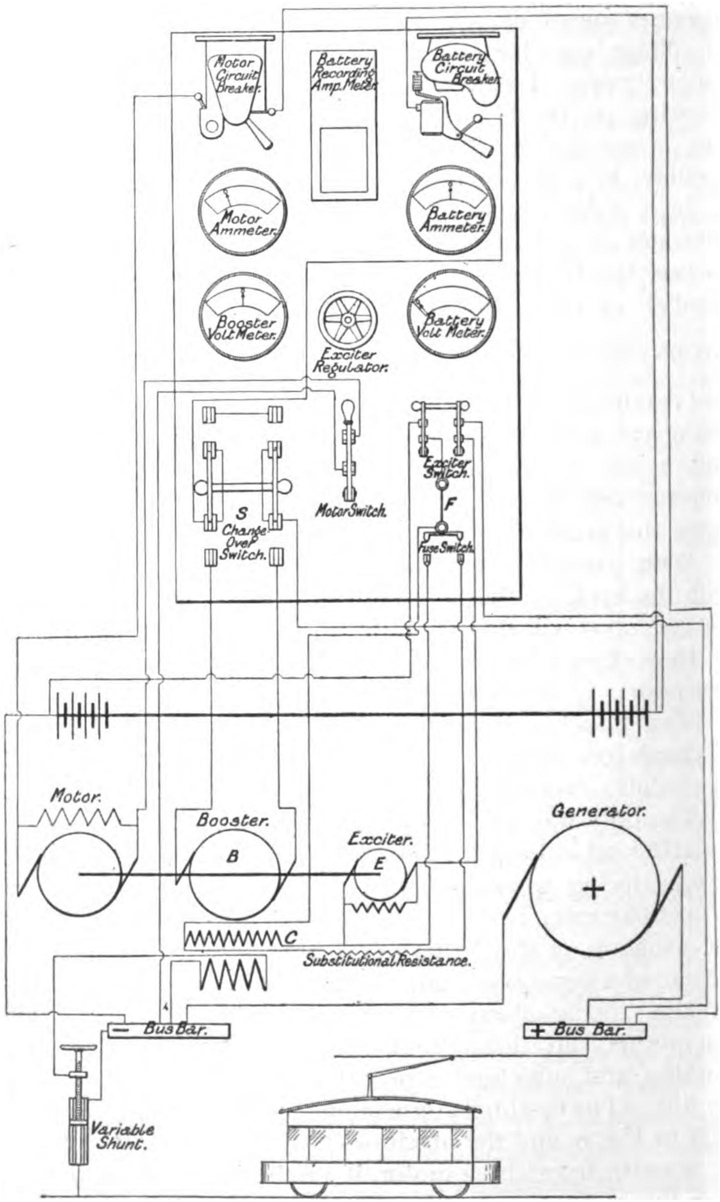
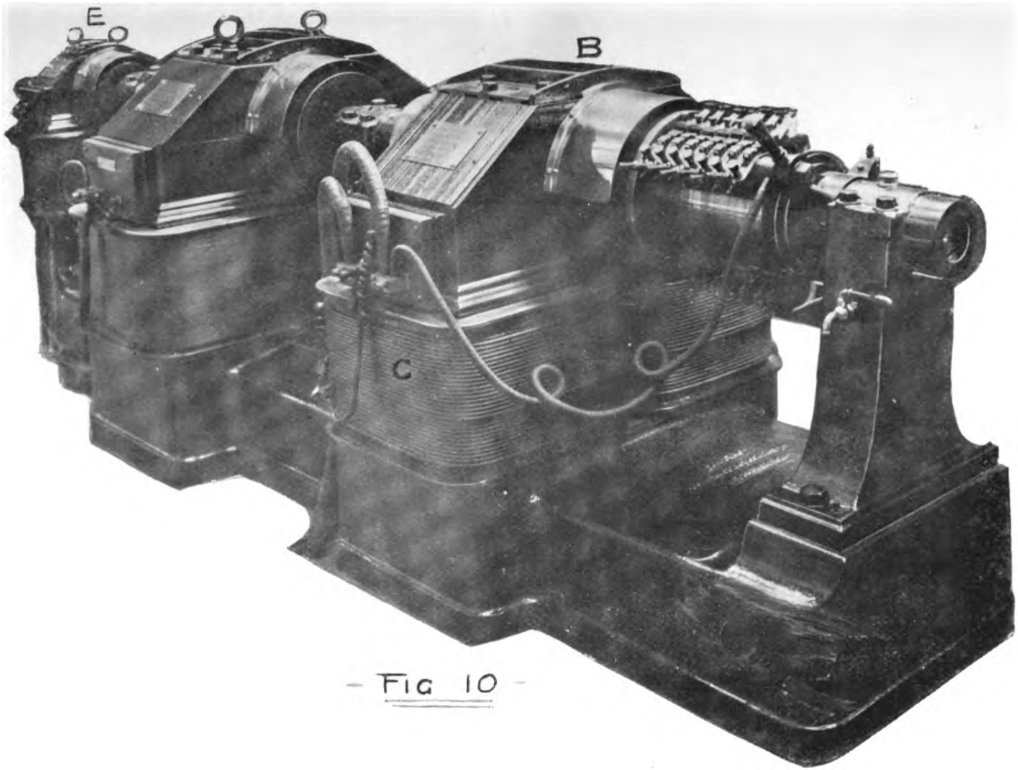


FIG. 9.—Arrangement of Reversible Booster operating Traction Load.

at constant speed is the same as the pressure across the ends of the exciter coil. The exciter E is a small generator giving 500 volts, and the necessary exciting current. This generator has a very small drop from no load to full load, which drop is corrected for by a series winding, its armature leads are coupled, one to the battery negative terminal, the other (the positive) to the positive battery terminal, by way of the exciter coil C. So long as the exciter and battery pressures are equal, no current will flow in the exciter coil, and hence the booster will give no pressure, but should the battery volts rise a current will move in C proportional to the difference of the pressures of the battery and of the exciter (which will be motored). The booster armature will then give a pressure equal to the rise of the battery pressure. Similarly, should the battery pressure fall, the booster will give a pressure equal to the fall, but will have its poles reversed, the exciter running as a generator and giving current to the battery. The booster therefore follows the variations of the battery pressure from the line pressure, and corrects for the variations, so as to maintain the line pressure constant whether the battery be charging or discharging. Generally, as will be readily seen, the exciter runs as a motor when charging, and as a generator when discharging, but since only 240 cells are used, occasionally, when the cells are low, charge begins at a less pressure than the 520 volts on the line, the booster then runs as a motor, and the motor as a generator, returning energy to the line; also when the battery is fully charged, the pressure is generally greater than the line pressure. Should the battery in this condition be called on to discharge, the booster opposes the discharge, and is motored; the motor then runs as a generator, and again returns energy to the line. The current variations in the motor amount to about 7 per cent of the maximum line variation. The booster fields being laminated, and being designed to work at a low induction so that the field strength is as nearly as possible proportional to the magnetising force the change of polarity is rapidly made, and the booster pressure varies very closely as the difference between the battery and exciter pressures. Such a booster connected in series with the battery will serve to maintain nearly constant the load on the generator, as it will nearly correct for all changes in the battery pressure. There will be times,

however, when the current through the booster armature is large, and the field very small; the armature reaction will then be an important factor in the working of such a machine. To overcome this, a coil connected in series with the armature is used, so that it opposes the reaction of the armature in whichever direction the current flows: this coil consists of a few turns only. In order to increase the pressure as the load on the line increases, a part of the feeder current is shunted round a coil on the booster fields in such a direction as to help the discharge or to oppose the charge, or a part of the feeder current may be taken round the exciter fields so as to raise the exciter pressure, or a part of the feeder may be taken round the motor fields, so that the greater the load becomes the greater is the motor speed, and hence also the exciter and booster pressure in the discharging direction. In working with shunt-wound generators there is a tendency for the motor to hunt, so that as the line load increases the battery does more than its share, the pressure therefore rises, and the motor runs faster; the booster pressure increases and the exciter pressure, and hence the tendency is to take still more load; a similar action occurs as the line load falls off. I have overcome this trouble by designing the motor so that an increase in pressure at its terminals strengthens the field in a greater proportion than usual, by designing the motor field on the same lines as the booster field, the result is entirely to check the hunting. The switch gear used with the booster is shown in Fig. 9. The switch *S* connects as shown on the diagram: in its upper position the battery is directly on the line, in the lower position the battery is connected through the booster armature; *F* is a shunt-breaking switch and fuse in the exciter circuit.

This booster is used in series with the battery at all times when the plant is running, or when regulation is necessary when the battery alone is driving the load. The curves, Figs. 11, 12, 13, show the results obtained. The curves shown are for a Friday and Saturday load, and hence indicate the working when the variations of the load are most violent. The curves have been plotted from readings taken on Elliott's Weston instruments, one observer reading each instrument. After operating the line from 11 p.m. on Thursday night, the night load consisting of late cars up to 1 a.m., and about 50 h.p. of motors at a colliery, and the early cars



- FIG 10 -

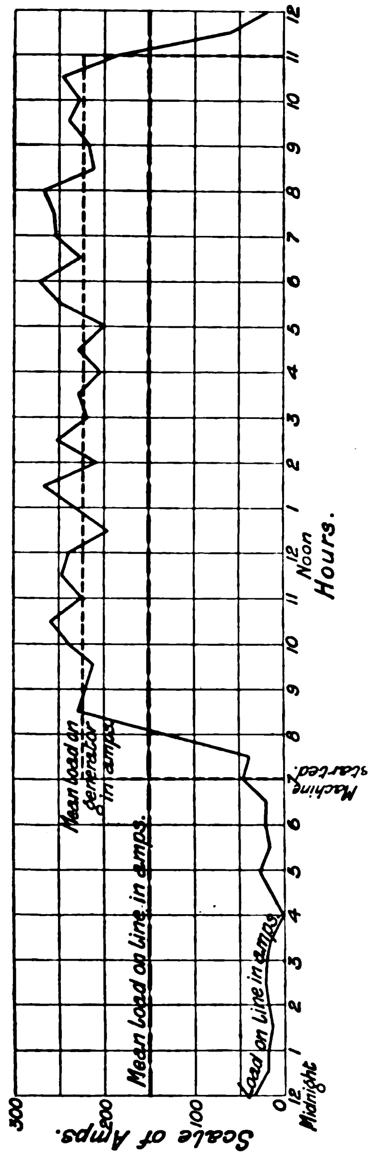


FIG. 6.—Traction Load Diagram. Generator and Battery.

central station is almost a necessity, at any rate, where a motor load exists. In such a case a shut down even for a few hours on Sunday is almost impossible, and on a week-day cannot be tolerated.

Apart from this use of batteries in the power station, there may arise occasions when the battery may be used in a substation at one or more important feeding points. About 15 per cent. of the copper put down in feeders is only required for a few hours each day for perhaps one month in the year, from the middle of December to the middle of January. This copper can be saved by using a battery in a substation, provided of course that a site can be found at not too great a cost. In addition to the saving in feeders, the economical area of distribution can be extended, and the pressure can be maintained more nearly constant. It is not possible to lay down general rules for the use of batteries in this way, but I now have a case where it is necessary to give supply at a point about three miles from the station. The extent of the supply will be about 100 kw. There is an excellent site for a substation about two and a half miles from the station, and a battery at this point works out at a less first cost than a boosted direct feeder, or a high-tension transmission scheme.

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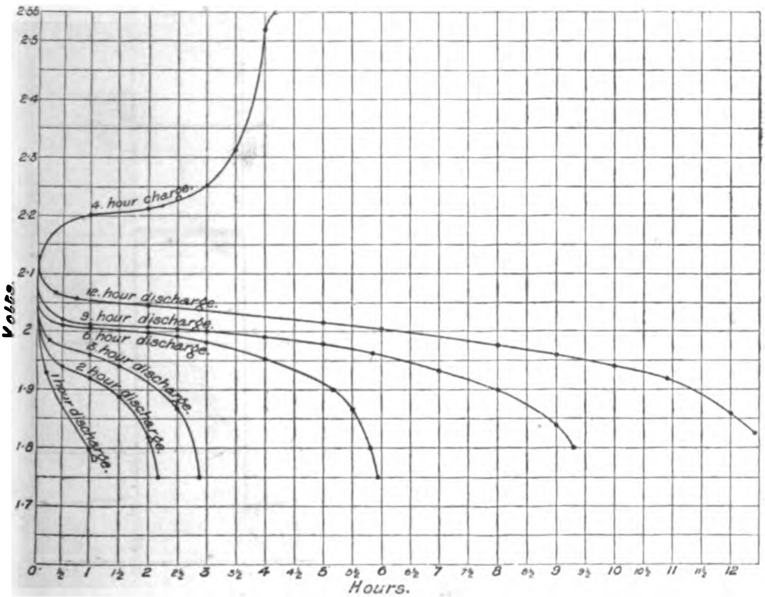

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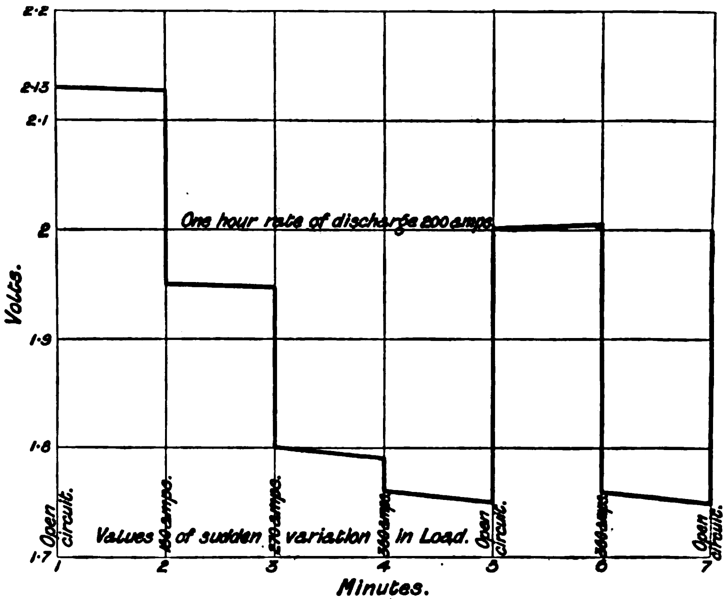

FIG. 8.—Variation in Volts of One Cell with Sudden Variation in the Load.

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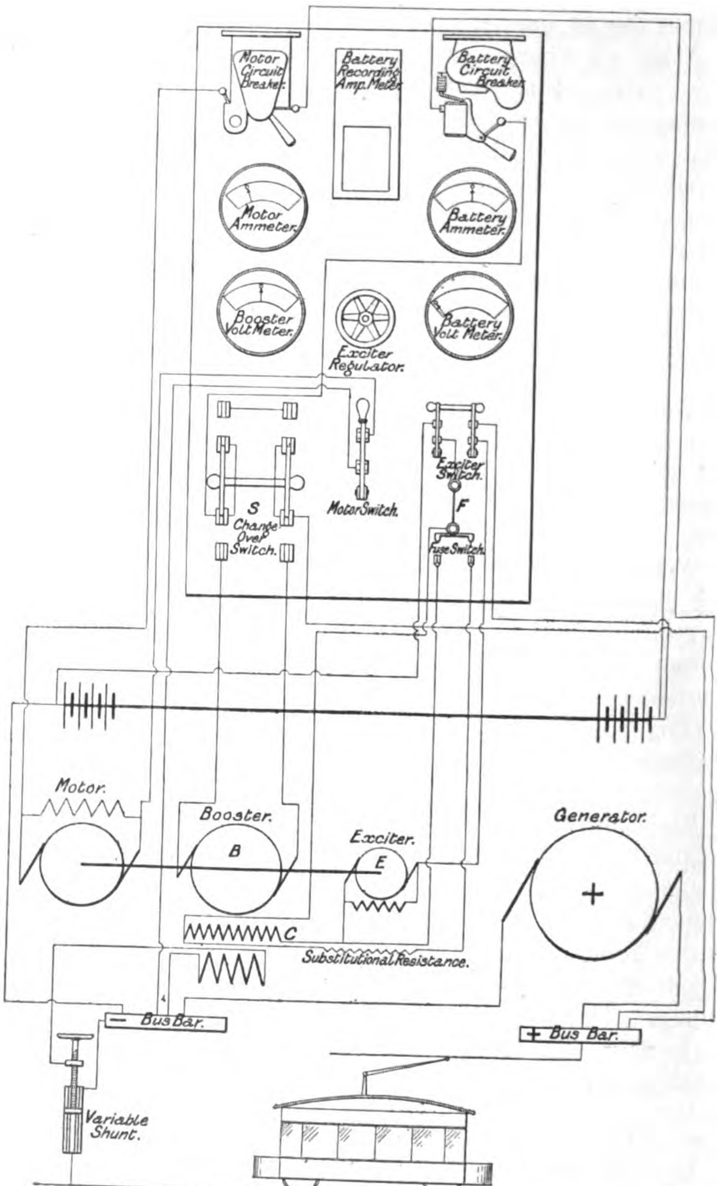
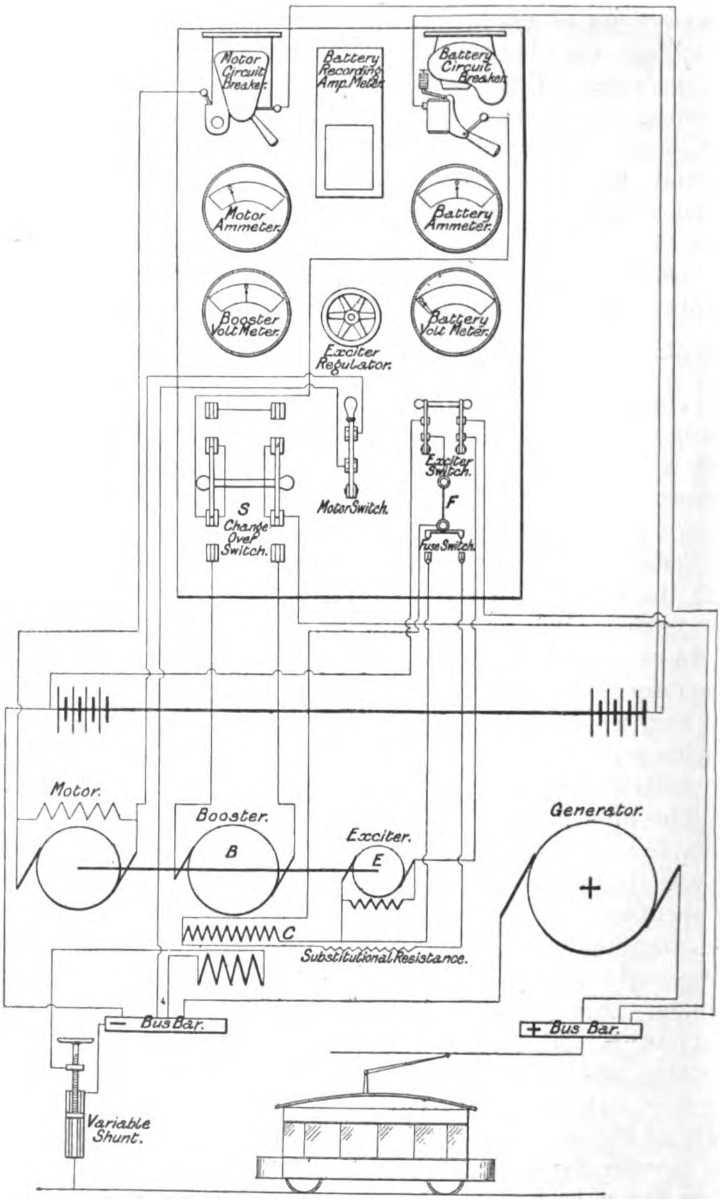


FIG. 9.—Arrangement of Reversible Booster operating Traction Load.

at constant speed is the same as the pressure across the ends of the exciter coil. The exciter *E* is a small generator giving 500 volts, and the necessary exciting current. This generator has a very small drop from no load to full load, which drop is corrected for by a series winding, its armature leads are coupled, one to the battery negative terminal, the other (the positive) to the positive battery terminal, by way of the exciter coil *C*. So long as the exciter and battery pressures are equal, no current will flow in the exciter coil, and hence the booster will give no pressure, but should the battery volts rise a current will move in *C* proportional to the difference of the pressures of the battery and of the exciter (which will be motored). The booster armature will then give a pressure equal to the rise of the battery pressure. Similarly, should the battery pressure fall, the booster will give a pressure equal to the fall, but will have its poles reversed, the exciter running as a generator and giving current to the battery. The booster therefore follows the variations of the battery pressure from the line pressure, and corrects for the variations, so as to maintain the line pressure constant whether the battery be charging or discharging. Generally, as will be readily seen, the exciter runs as a motor when charging, and as a generator when discharging, but since only 240 cells are used, occasionally, when the cells are low, charge begins at a less pressure than the 520 volts on the line, the booster then runs as a motor, and the motor as a generator, returning energy to the line; also when the battery is fully charged, the pressure is generally greater than the line pressure. Should the battery in this condition be called on to discharge, the booster opposes the discharge, and is motored; the motor then runs as a generator, and again returns energy to the line. The current variations in the motor amount to about 7 per cent of the maximum line variation. The booster fields being laminated, and being designed to work at a low induction so that the field strength is as nearly as possible proportional to the magnetising force the change of polarity is rapidly made, and the booster pressure varies very closely as the difference between the battery and exciter pressures. Such a booster connected in series with the battery will serve to maintain nearly constant the load on the generator, as it will nearly correct for all changes in the battery pressure. There will be times,



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however, when the current through the booster armature is large, and the field very small; the armature reaction will then be an important factor in the working of such a machine. To overcome this, a coil connected in series with the armature is used, so that it opposes the reaction of the armature in whichever direction the current flows: this coil consists of a few turns only. In order to increase the pressure as the load on the line increases, a part of the feeder current is shunted round a coil on the booster fields in such a direction as to help the discharge or to oppose the charge, or a part of the feeder current may be taken round the exciter fields so as to raise the exciter pressure, or a part of the feeder may be taken round the motor fields, so that the greater the load becomes the greater is the motor speed, and hence also the exciter and booster pressure in the discharging direction. In working with shunt-wound generators there is a tendency for the motor to hunt, so that as the line load increases the battery does more than its share, the pressure therefore rises, and the motor runs faster; the booster pressure increases and the exciter pressure, and hence the tendency is to take still more load; a similar action occurs as the line load falls off. I have overcome this trouble by designing the motor so that an increase in pressure at its terminals strengthens the field in a greater proportion than usual, by designing the motor field on the same lines as the booster field, the result is entirely to check the hunting. The switch gear used with the booster is shown in Fig. 9. The switch *S* connects as shown on the diagram: in its upper position the battery is directly on the line, in the lower position the battery is connected through the booster armature; *F* is a shunt-breaking switch and fuse in the exciter circuit.

This booster is used in series with the battery at all times when the plant is running, or when regulation is necessary when the battery alone is driving the load. The curves, Figs. 11, 12, 13, show the results obtained. The curves shown are for a Friday and Saturday load, and hence indicate the working when the variations of the load are most violent. The curves have been plotted from readings taken on Elliott's Weston instruments, one observer reading each instrument. After operating the line from 11 p.m. on Thursday night, the night load consisting of late cars up to 1 a.m., and about 50 h.p. of motors at a colliery, and the early cars

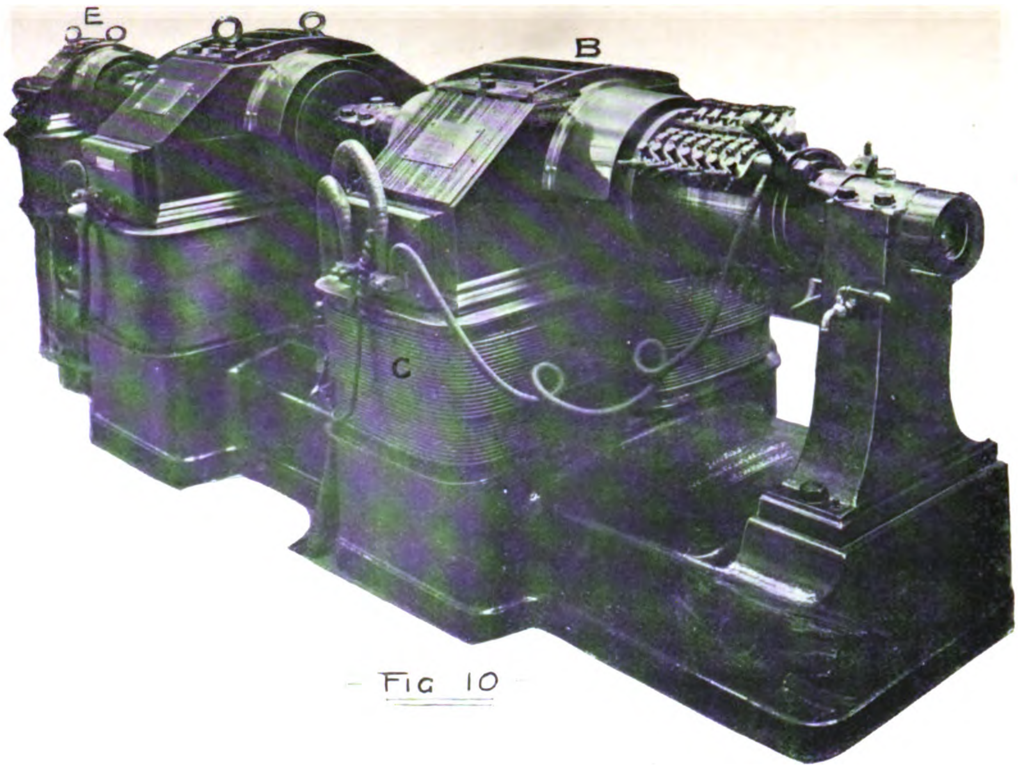

FIG 10

however, when the current through the booster armature is large, and the field very small; the armature reaction will then be an important factor in the working of such a machine. To overcome this, a coil connected in series with the armature is used, so that it opposes the reaction of the armature in whichever direction the current flows: this coil consists of a few turns only. In order to increase the pressure as the load on the line increases, a part of the feeder current is shunted round a coil on the booster fields in such a direction as to help the discharge or to oppose the charge, or a part of the feeder current may be taken round the exciter fields so as to raise the exciter pressure, or a part of the feeder may be taken round the motor fields, so that the greater the load becomes the greater is the motor speed, and hence also the exciter and booster pressure in the discharging direction. In working with shunt-wound generators there is a tendency for the motor to hunt, so that as the line load increases the battery does more than its share, the pressure therefore rises, and the motor runs faster; the booster pressure increases and the exciter pressure, and hence the tendency is to take still more load; a similar action occurs as the line load falls off. I have overcome this trouble by designing the motor so that an increase in pressure at its terminals strengthens the field in a greater proportion than usual, by designing the motor field on the same lines as the booster field, the result is entirely to check the hunting. The switch gear used with the booster is shown in Fig. 9. The switch *S* connects as shown on the diagram: in its upper position the battery is directly on the line, in the lower position the battery is connected through the booster armature; *F* is a shunt-breaking switch and fuse in the exciter circuit.

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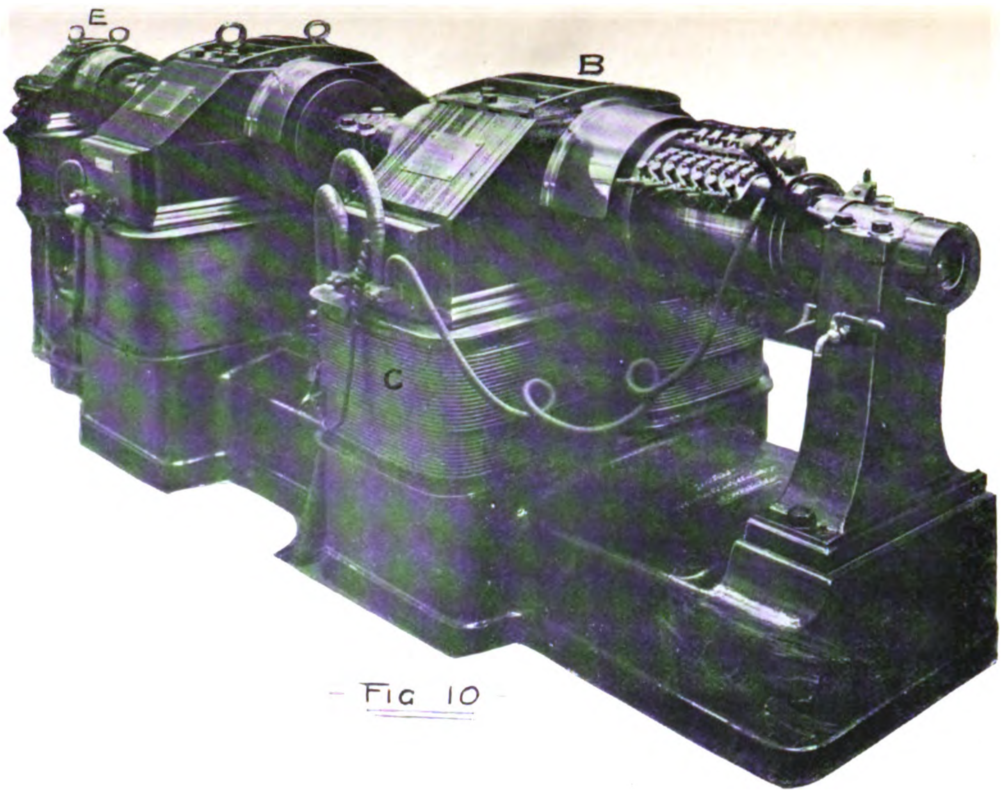


FIG 10

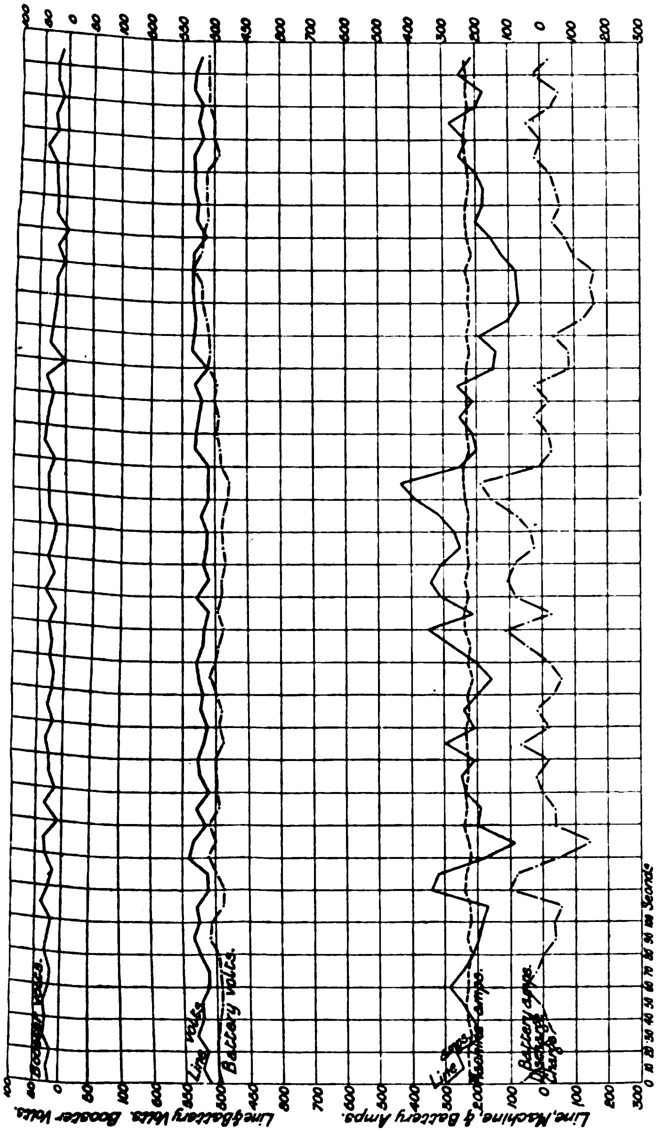
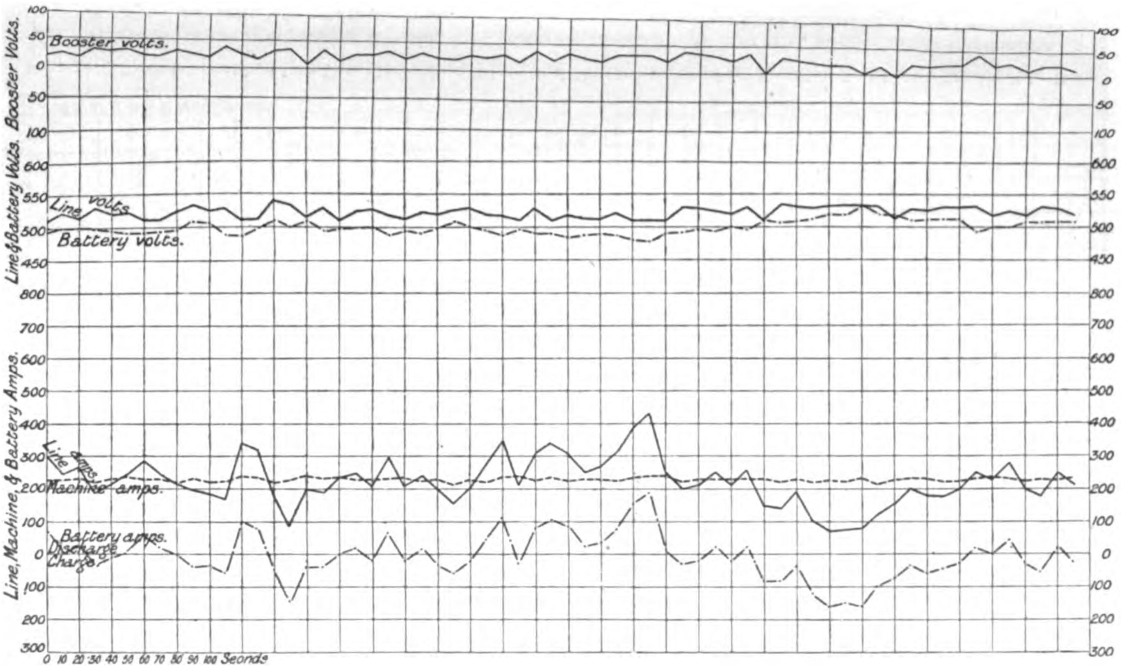


FIG. 11.—Curves showing Load on Generator, Line, and Battery, operating Traction Load with Reversible Booster.

Generator—125 K.W. Shunt Wound.
Battery—240 cells, 450 amps. per hour.
Booster—25 K.W. capacity.

Cars on Line—1 with 2·25 H.P. Motors for 52 Passengers.
" " 19 with 2·35 H.P. Motors for 79 Passengers.
(Readings taken Friday, March 1st, 1901, Morning.)



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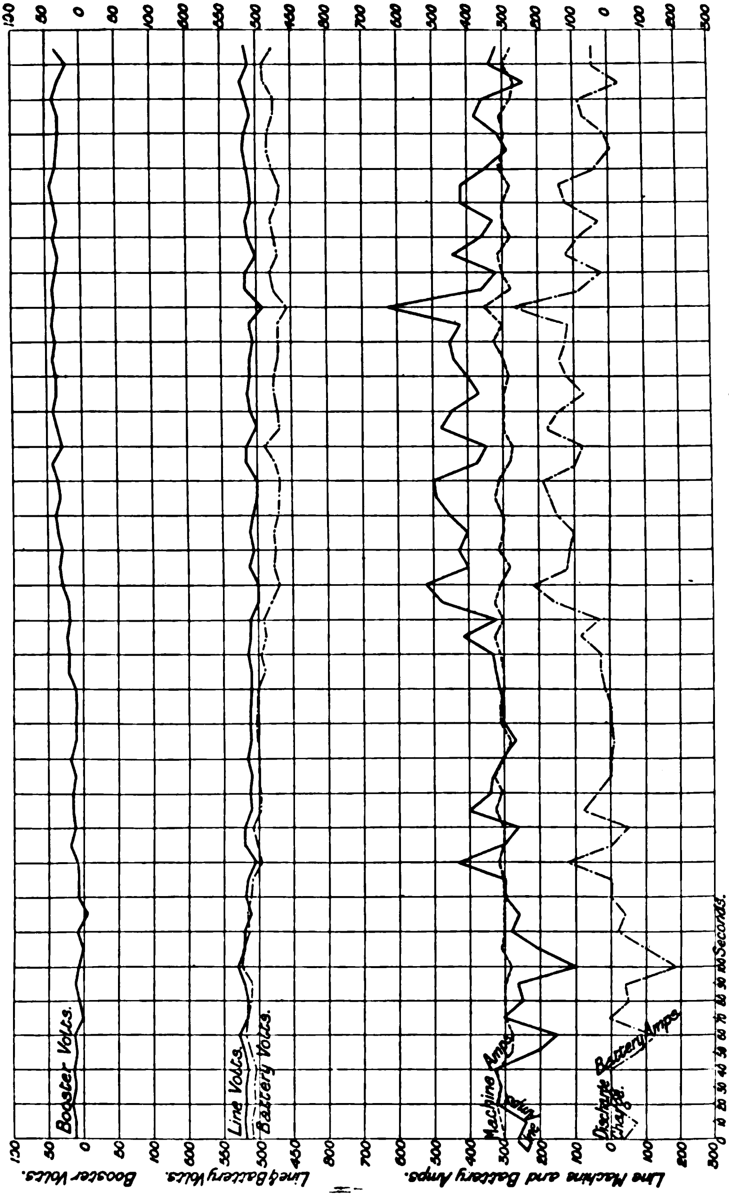
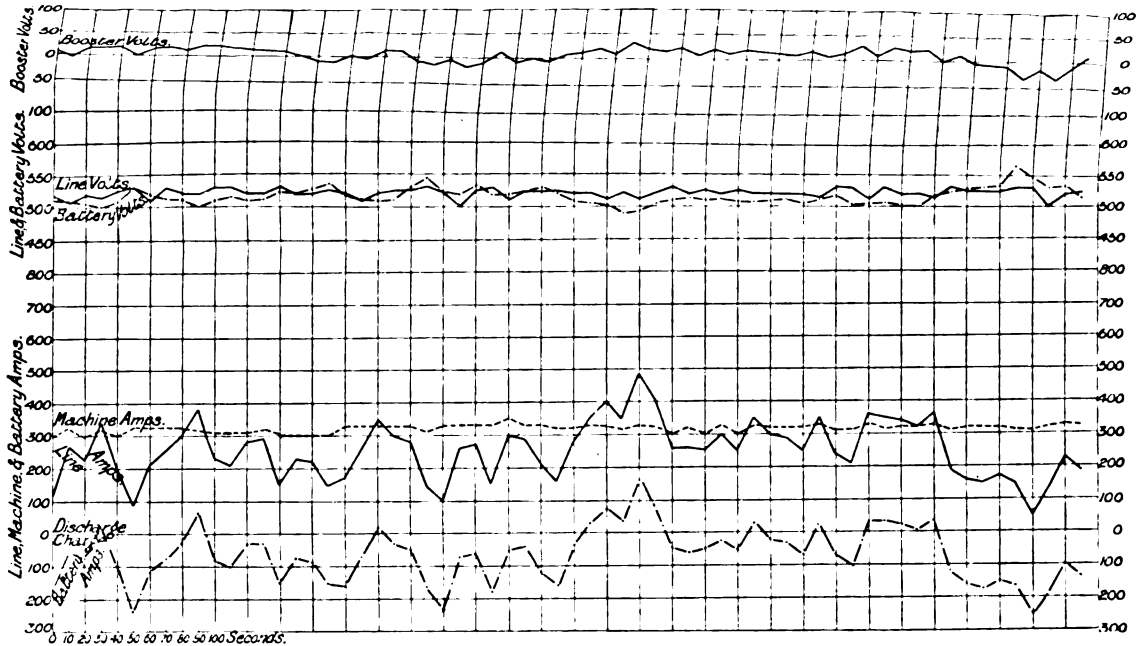


FIG. 12.—Curves showing Load on Generator, Line, and Battery, operating Traction Load with Reversible Booster.

Generator—210 K.W. Shunt Wound.
Battery—240 cells, 450 amps. per hour.
Booster—25 K.W. capacity.

Cars on Line—2 with 2·25 H.P. Motors for 52 Passengers.
" 23 with 2·35 H.P. Motors for 79 Passengers.
(Readings taken Saturday, March 2nd, 1901, Afternoon.)



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„ „ 21 with 2·35 H.P. Motors for 79 Passengers.
(Readings taken Friday. March 1st, 1901, Afternoon.)

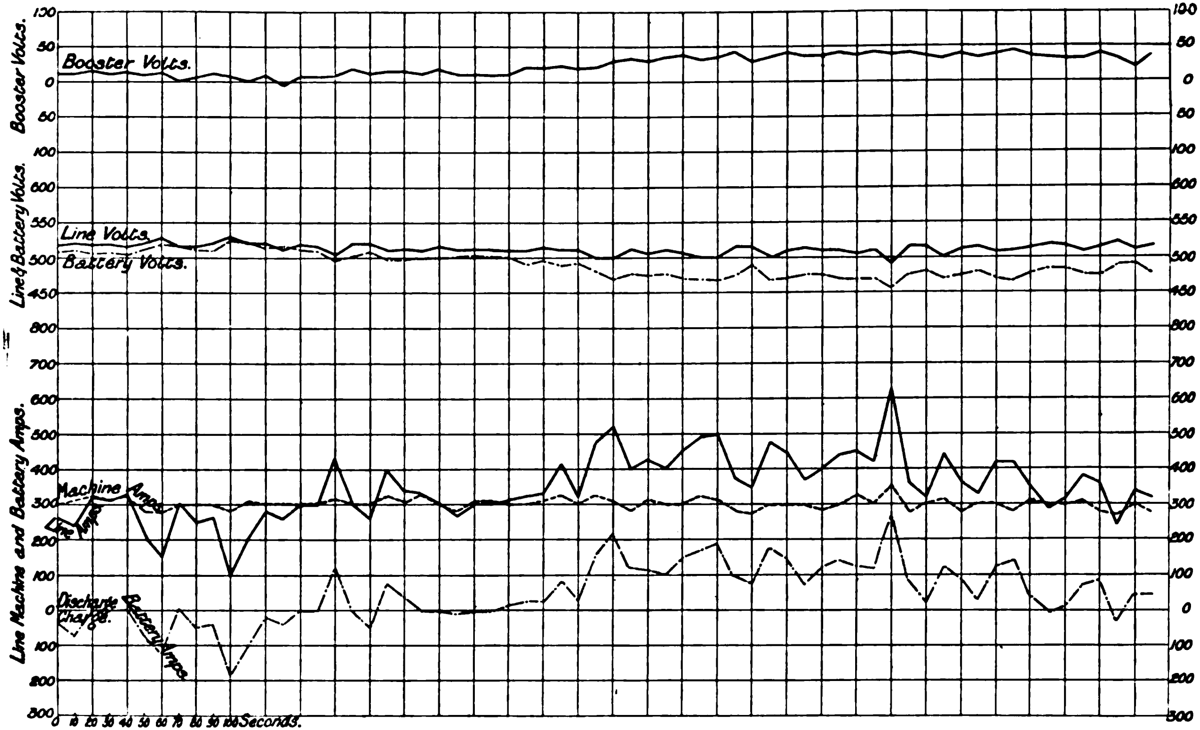


FIG. 12.—Curves showing Load on Generator, Line, and Battery, operating Traction Load with Reversible Booster.

Generator—210 K.W. Shunt Wound.
Battery—240 cells, 450 amps. per hour.
Booster—25 K.W. capacity.

Cars on Line—2 with 2·25 H.P. Motors for 52 Passengers.
" " 23 with 2·35 H.P. Motors for 79 Passengers.
(Readings taken Saturday, March 2nd, 1901, Afternoon.)

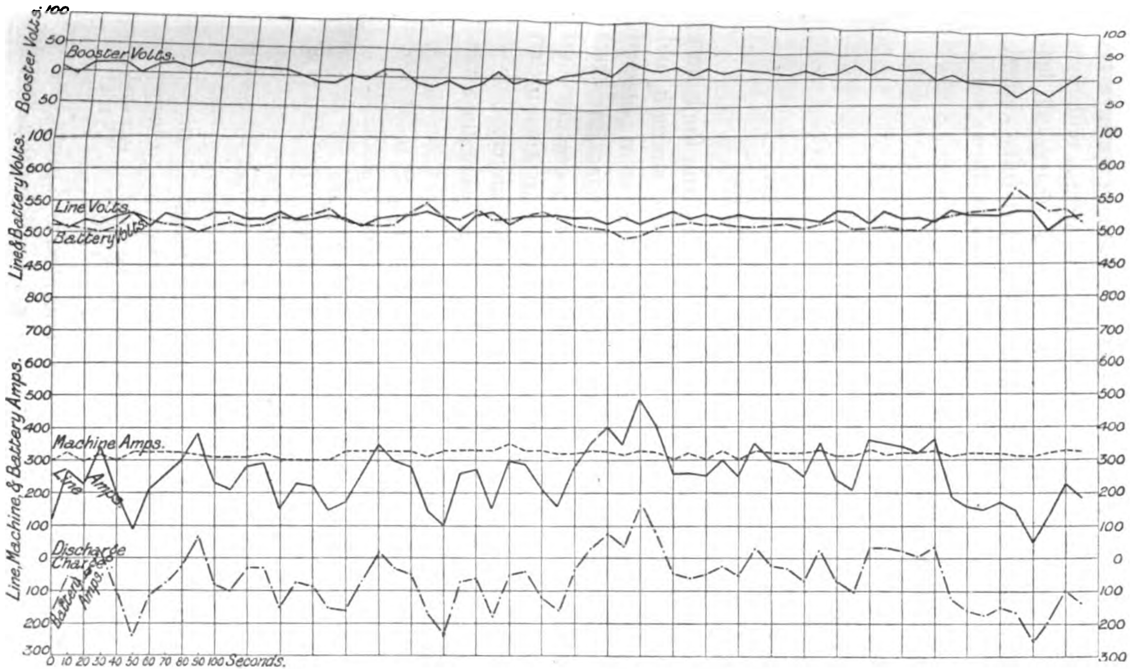


FIG. 13.—Curves showing Load on Generator, Line, and Battery, operating Traction Load with Reversible Booster.

Generator—210 K.W. Shunt Wound.
Battery—240 cells, 450 amps. per hour.
Booster—25 K.W. capacity.

Cars on Line—1 with 2·25 H.P. Motors for 52 Passengers.
" " 21 with 2·35 H.P. Motors for 79 Passengers.
(Readings taken Friday, March 1st, 1901, Afternoon.)

from 4-30 a.m. to 6-30 a.m. on Friday morning, a 125 kw. shunt-wound unit was connected, and run at full load till 2 p.m., the battery during the time from 6-30 to 8 a.m. gaining a certain amount of charge; from 2 p.m. a 215 kw. shunt-wound unit took the load running with from 300 to 350 amperes, the battery gaining in charge till shutting down time at 11 p.m., when it ended fully charged. The figures relating to the day's work are as follows:—

Units generated	amounted to	2,119
„ to line	„ „	2,045
Battery charge	„ „	272
„ discharge	„ „	318
Used by booster motor	...	66
Maximum load on line	...	382 kw.
Minimum „ „ „	...	20 kw.

There is some difficulty in accurately metering the battery units owing to the violent changes in the strength and direction of the current. The above figures were obtained from two Thomson-Houston watt-hour meters in series provided with pawls to admit of revolution in one direction only; the generator units were measured on an Aron meter, and the booster and line units on Hookham meters.

From March 2nd to March 31st the figures obtained were as follows:—

Units Generated ...	65,615
„ sent to line ...	61,665
„ used by booster	2,034
„ Charge... ...	10,517
„ Discharge ...	8,560

Giving the following percentages:—

Units Sold. Generated. Per cent.	*Booster.* Generated. Per cent.	*Charge.* Generated. Per cent.	*Disch.* Sold. Per cent.	*Disch.* Charge. Per cent.
94	3·1	16	13·9	81·4

The difference between units generated and units metered to line, is, of course, due to the units used by the booster motor and the units lost in the battery; the figures it will be noted check one another very closely, the former figure is 3,950 units and the latter 3,991 units. The slight discrepancy is accounted for by the fact that the units metered to the line

are read on an ampere-hour meter, and an error in the line pressure would affect the figure; all the other readings are taken on watt-hour meters. The battery efficiency is really rather higher than 81·4 per cent. At the beginning of the month the average specific gravity was 1·205 when the cells were fully charged; at the end of the month the specific gravity had risen to 1·210, showing that more charging was given than would have been necessary if sufficient charge had been given during the previous month. The small percentage of energy taken by the booster motor is confirmed over a long period as shown by the additional figures in the Appendix. The percentage of the whole number of units generated which passed through the battery is also rather surprising, considering that the battery takes more than one half of the maximum line load. Referring to the Appendix figures, I should say that the booster described in the paper was put to work in the middle of August. Before that time a small booster of the same type was used with a battery giving 100 amperes at the one-hour rate; this battery frequently gave discharges of 170 amperes. This was the first booster made of the type described, and was of an experimental nature. Unfortunately I had not arranged for the metering of all the units at that time, and therefore no figures relating to its operation are available.

Figs. 14, 15, 16, 17 show curves photographically reproduced from charts taken from Elliott recording instruments. Fig. 14 shows the action of the battery without the reversible booster, the line pressure being kept by hand from 490 to 550 volts; without hand regulation the variation on a shunt-wound generator would be altogether too great if the battery were worked anywhere near the one-hour rate. Figs. 15, 16, 17 show the operation with the booster in the ordinary way of working. Unfortunately the instrument on the generator was not of the latest type fitted with a dash-pot, so that the quick changes which occur are somewhat magnified. Errors in the engine governor also account for some variations.

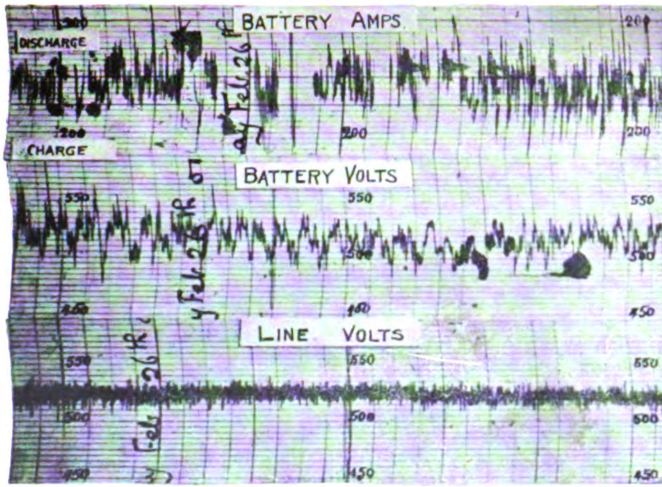
I should here note that the ultimate object of the booster is to correct for the varying characteristic of the battery: when in a partly charged condition, the battery characteristic is a falling one, somewhat similar to the characteristic of a shunt-wound generator. The characteristic, however, varies according to the state of charge of the

battery. The reversible booster described serves to correct for the varying nature of the battery characteristic so as to make the characteristic of the battery and booster the same whatever the state of charge, and to make it either falling or flat, or rising over a wide range. By making the characteristic flat, the load on a shunt-wound generator working in parallel with the boosted battery will be nearly constant. By adjusting the booster so that the characteristic closely follows the characteristic of the generator, whether shunt or compound wound, the load will be shared by the battery as in the case of two generators in parallel.

There is one other point I should here refer to, that is the nature of the fluctuations of the current taken by the motor driving the booster. Since the number of cells used is 240, the boost on the top charge amounts to 100 volts, that is, the pressure is from 600 to 620 volts on the cells when they are fully charged. The least pressure to which the battery falls on the heaviest discharges is 440 volts, the boost on charge is therefore greater than on discharge, hence with the same current the motor takes more driving on charge than on discharge; and therefore, with the steady load on the generator, the charging current is never as great as the discharging current, as will be seen from the curves. The greatest observed current taken by the motor is 70 amperes, but this is unusual, the normal maximum not exceeding 50, or about 7 per cent. of the maximum load.

The battery used consists of 240 cells, giving 450 amperes at a one-hour rate of discharge. The booster is rated for 200 amperes continuously, and will carry 450 amperes momentarily; the brushes work without lead, and do not spark even when a current of 200 amperes is passing without any field.

In considering the use of batteries in connection with large plant operating roads with upwards of 400 cars, it is necessary to take into account the above-mentioned fact, that the load will be a fairly even one, and with properly designed engines very little improvement in economy can be attained by a further levelling of the load by a battery. There may be special cases, for instance, where a small all-night service is worked, or where a peak, due to extra cars, exists at stated hours, which a battery could carry, and so save the use of extra boilers or engines



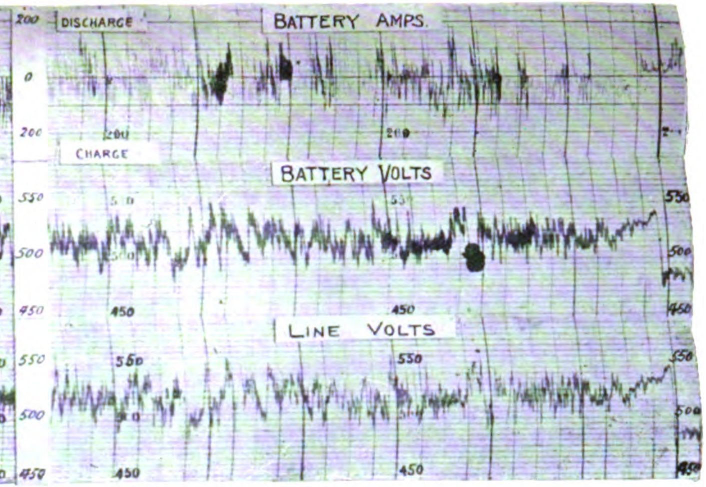
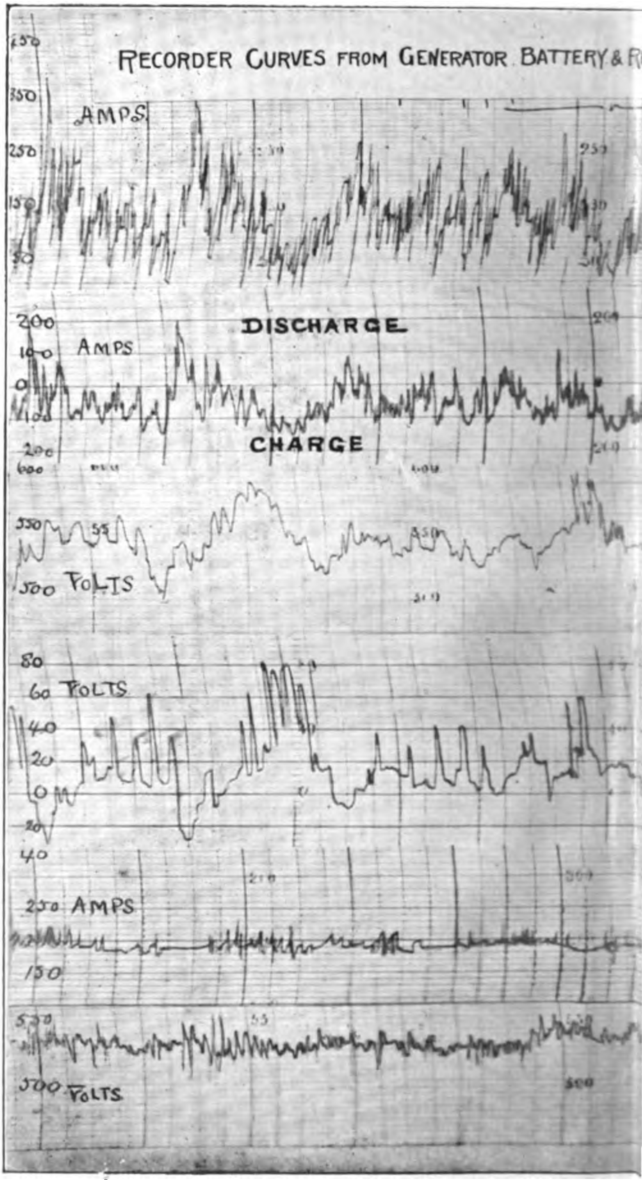


FIG. 15.—Working with Booster.

FIG. 14.—Working without Booster.

Recorder Curves for Traction Load worked with Battery and Reversible Booster.



RECORDER CURVES FROM GENERATOR BATTERY & F
AMPS
DISCHARGE
AMPS
CHARGE
VOLTS
VOLTS
AMPS
VOLTS

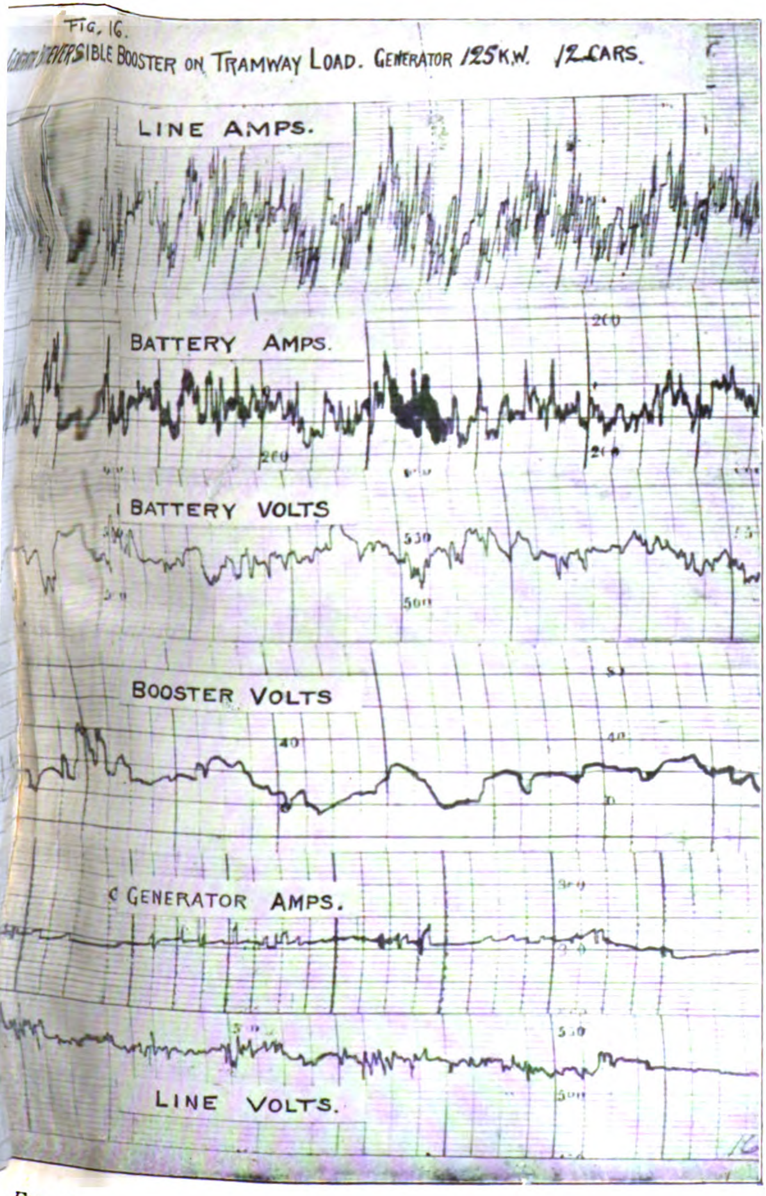
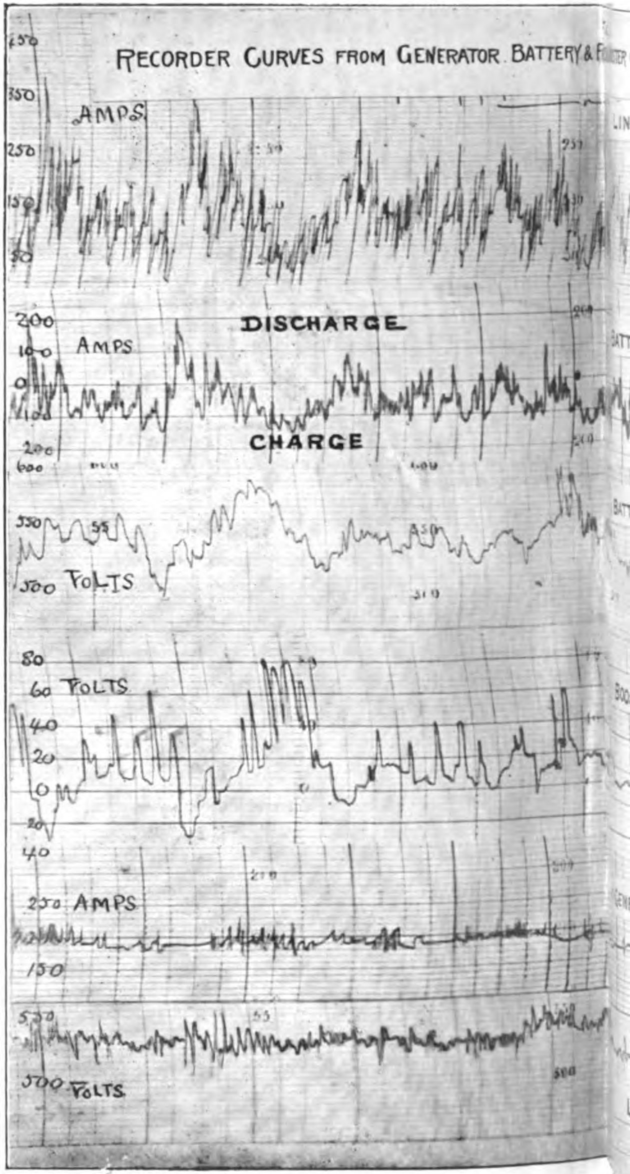


Fig. 16.
REVERSIBLE BOOSTER ON TRAMWAY LOAD. GENERATOR 125 K.W. 12 CARS.
LINE AMPS.
BATTERY AMPS.
200
200
BATTERY VOLTS
530
500
BOOSTER VOLTS
40
40
GENERATOR AMPS.
530
500
LINE VOLTS.

Fig. 16



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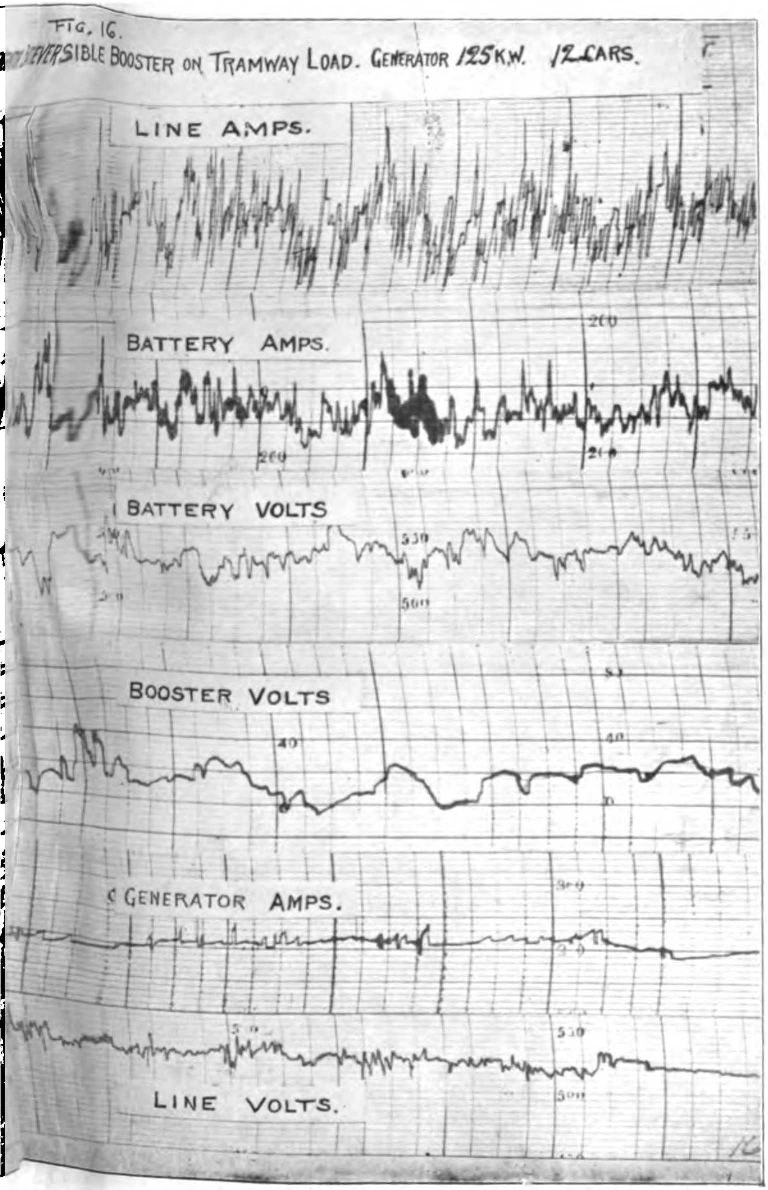


FIG. 16.
SIBLE BOOSTER ON TRAMWAY LOAD. GENERATOR 125 K.W. 12 CARS.
LINE AMPS.
BATTERY AMPS.
200
BATTERY VOLTS
530
500
BOOSTER VOLTS
40
GENERATOR AMPS.
530
500
LINE VOLTS.

FIG. 16.

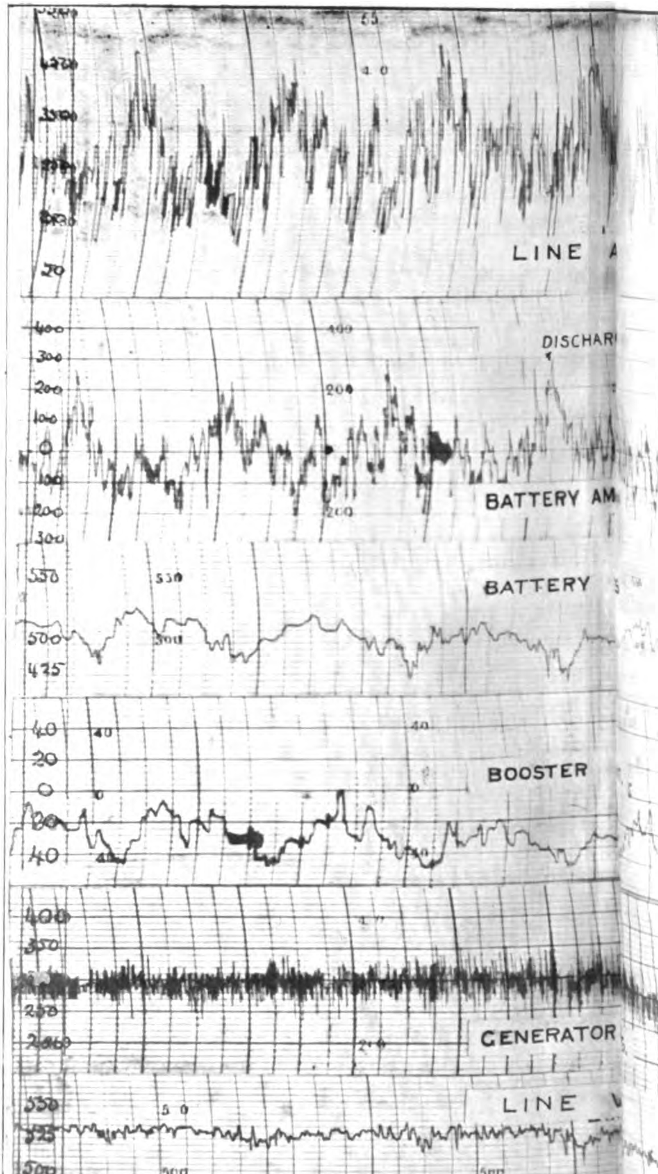
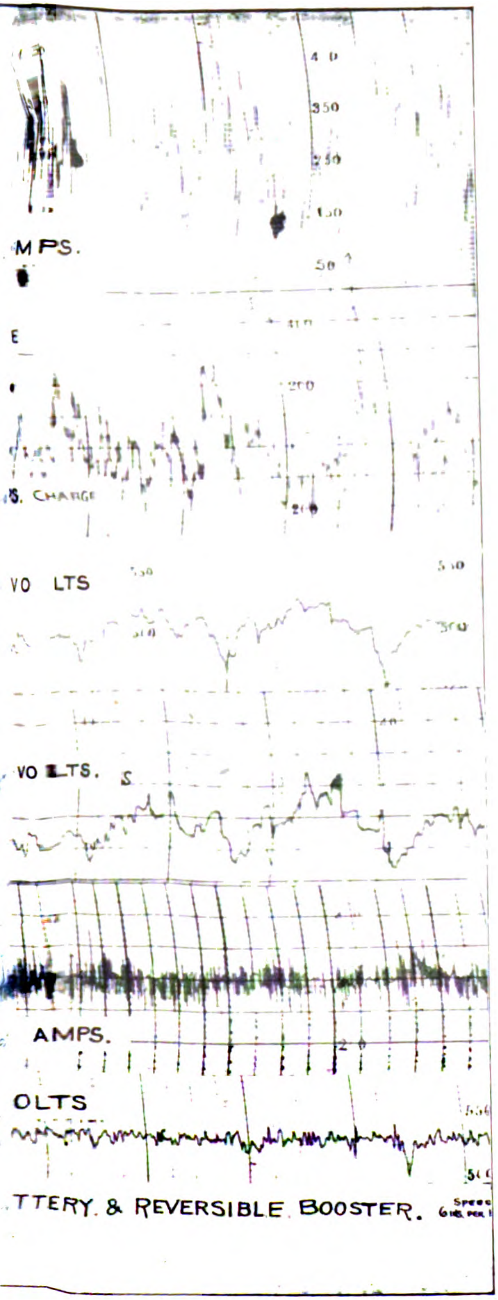
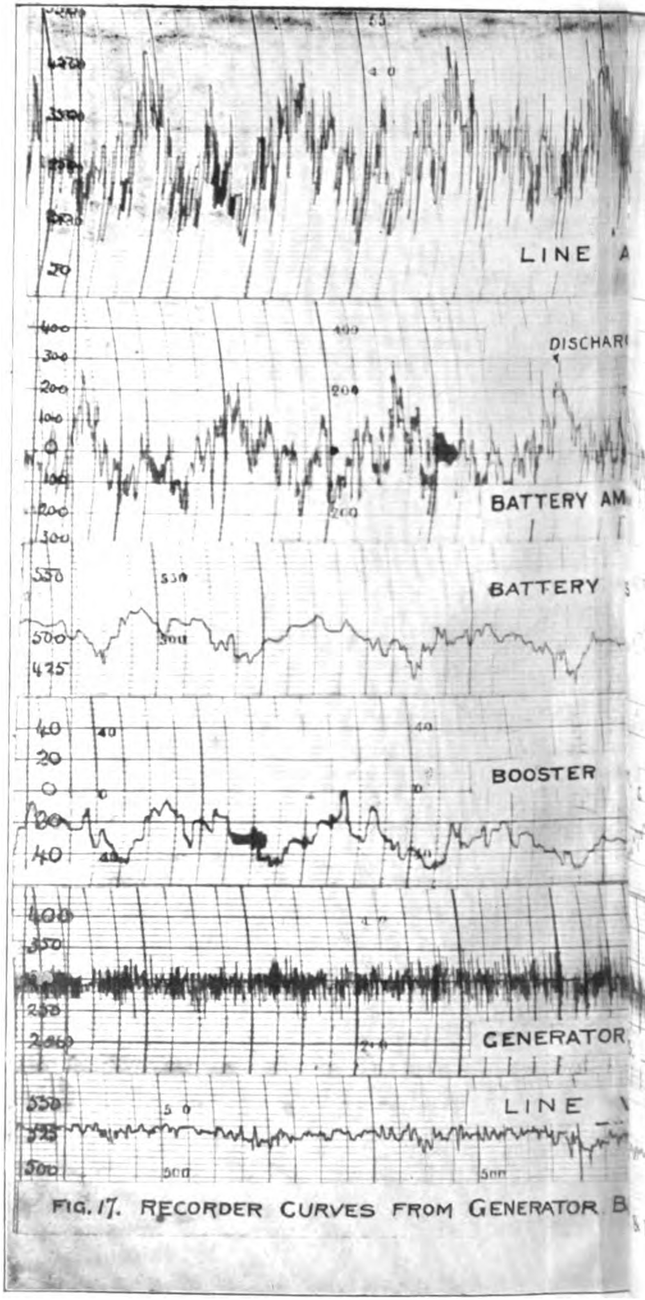


FIG. 17. RECORDER CURVES FROM GENERATOR B

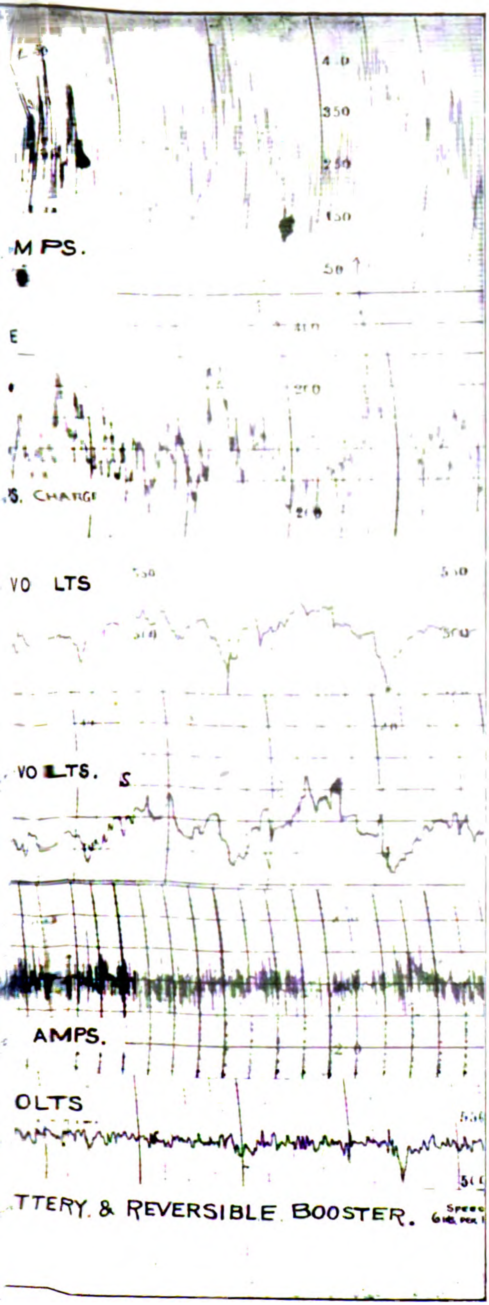
FIG. 17.


MPS.
CHARGE
VO LTS
VO LTS.
AMPS.
OLTS
TTERY & REVERSIBLE BOOSTER.



LINE A
DISCHAR
BATTERY AM
BATTERY
BOOSTER
GENERATOR
LINE V
FIG. 17. RECORDER CURVES FROM GENERATOR B

FIG. 17


4.0
350
250
150
MPS.
50
S. CHARGE
VO LTS
550
VO LTS.
AMPS.
OLTS
TTERY & REVERSIBLE BOOSTER.

for only one or two hours. In general, however, I am inclined to consider that the central station is not the correct place for a battery to be used with plant for this size of road. Consider the case where a system of town tramways, operating upwards of 100 cars, is driven from a single station situated reasonably near to the centre of the load, several of the routes running out some six or more miles in various directions from the centre. Each route should be fed by its own feeders to obviate any breakdown on one route affecting the remainder; each route might account for 30 or 40 cars, the load on each set of feeders would be of the same character as the load on a small system with a load-factor of not more than 25 per cent. There is no doubt, therefore, that given suitable sites, batteries in substations worked as described above would serve to keep the load on the feeders constant, and since less than a third of the maximum current would be carried by the rails, the use of boosted rail-feeders would be obviated.

The same arguments also apply to the case where the power-station is so far outside the area as to necessitate the use of converted high-tension currents: by using a suitable battery in the substations the load on the converters could be kept constant, the rotaries would then operate more perfectly; they need not be of such great capacity as without batteries, and the high-tension feeders could be designed to carry the mean current instead of the maximum.

A power station supplying energy to a railway, as distinguished from a tramway, will, in general, carry a load of the same character as that of a small tramway plant; but the fluctuations of the load will be of greater amount due to the greater energy taken in starting the heavier vehicles. At the same time, it is more easy to arrange the running schedule for a railway than for a street tramway, so that only a few cars or trains start or ascend heavy grades simultaneously; the stops generally are less frequent, and the road is flatter than that obtaining in the ordinary tramway. The distances run will probably, however, be greater, and therefore the right place for batteries on a railway system will be in substations situated near the load centres.

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Batteries in Combined Stations.

In combined stations, supplying both to a three-wire 460 to 500-volt lighting network and to a 500-volt tramway system, the boosting system can be used in a convenient way: 240 cells are sufficient with the booster just described for a tramway circuit at 500 to 550 volts, and are equally suitable for a 460-volt lighting system. Since no regulating connections are used two identical batteries may be installed, each working on to its own panel on the switchboard, the instruments consisting of a double-pole throw-over switch, a double-pole fuse, two voltmeters to show battery and line volts respectively, and an ammeter reading both sides of zero: leads should also go to the middle point on each battery, so that the middle point may be connected to the middle lighting bus bar when desired. By this arrangement either or both batteries may be used on the lighting or traction circuits, and one battery may be charged on either circuit and discharged on the other. In the event of no all-night cars being run, both batteries may be used to drive the lighting load.

A very great advantage of working batteries as described on traction loads is that an ordinary shunt-wound generator driven by an engine without any great weight of flywheel may be used, thus enabling the generators to be worked without alteration on the lighting bus bars, and saving the cost and complication of equalising gear.

It seems hardly necessary to point out how much easier is the work put on the running plant, when batteries are used so as to give it a steady load, compared with driving the cars direct when all the fluctuations come on, and have to be dealt with by the engine.

General Considerations.

It is convenient to summarise the points referred to under the separate heads of :—

1. Batteries in Lighting Stations.
2. Batteries in Traction Stations.
3. Batteries in Combined Stations.

In the first case the battery should be used to serve as a

regulator for the pressure, to enable the individual units to be fully loaded without the use of several graded sizes, and to enable the number of units to be decreased; that is to say, to enable a few units of greater and of uniform size to be adopted, instead of the many graded units usually installed, and to improve the plant load factor over the whole year, especially to enable the steam raising and distributing plant to be more uniformly worked; and, in special cases, to effect a saving in feeder copper, and to enable the area of supply to be economically extended.

In the second case, although the engines may be working only at one-third to one-half of their load, the boilers during working hours are economically loaded, and a battery will effect a saving of fuel, from the boiler point of view, by serving to operate the all-night load, shortening the boiler working hours, and ensuring that, when the engines are running, the boilers are working at a good load. The saving of one hour's steaming in the morning, and at night when only a few cars are out, will also effect a considerable saving in fuel. The battery, however, enables the engines to be run nearly at full load at all times, it thus makes the steam used per unit less, and also saves considerable wear and tear of plant; it enables, especially in small systems, a greater number of cars to be operated by a given plant, twenty light cars being easily worked by a 125 kw. unit. Used in substations, the battery should effect a large saving in copper, both for line and rail feeders, it should frequently enable negative boosters to be dispensed with, and it permits of the working of long routes with direct supply at the standard pressure.

In combined stations the use of a battery worked in conjunction with a reversible booster enables all the plant to be of the same pattern, shunt-wound generators operating quite as well as compound ones. The arrangement of two identical batteries enables an interchange of energy to be made between the traction and lighting units, a point of value especially in stations of small and moderate size.

The special points to be considered in designing the battery, with a view to its economical use, are: (1) The capital cost as compared with that of plant. For a lighting station this should be worked out at not less than the three-

hour rate of discharge, and at this rate will be found not to differ much from that of plant of the same capacity.

For power stations the capital cost may be worked out at the one-hour rate of discharge, and will be less than the cost of corresponding plant.

The cost of battery depreciation is an exceedingly difficult figure to arrive at. I find that the cost of replating throughout for a battery in lead boxes, or in stout wood lead-lined boxes, amounts to about one-half the cost of the battery, when allowance is made for old material. Giving the plates a life of six years, this represents about 7 per cent. per annum on the cost of the battery. Allowing for complete replating every six years, the repairs on a battery are a negligible amount, and the wages account is also exceedingly small, the labour involved being for filling up the cells every week or fortnight, and for taking the specific gravities every week as before described.

The chief considerations, therefore, are the saving in fuel due to working with a better load factor—especially working the steam-raising plant at a better load factor—the saving in wages through working the running plant a reduced number of hours; and, finally, whether the saving effected through these causes makes up for the cost of the lost energy in the battery itself.

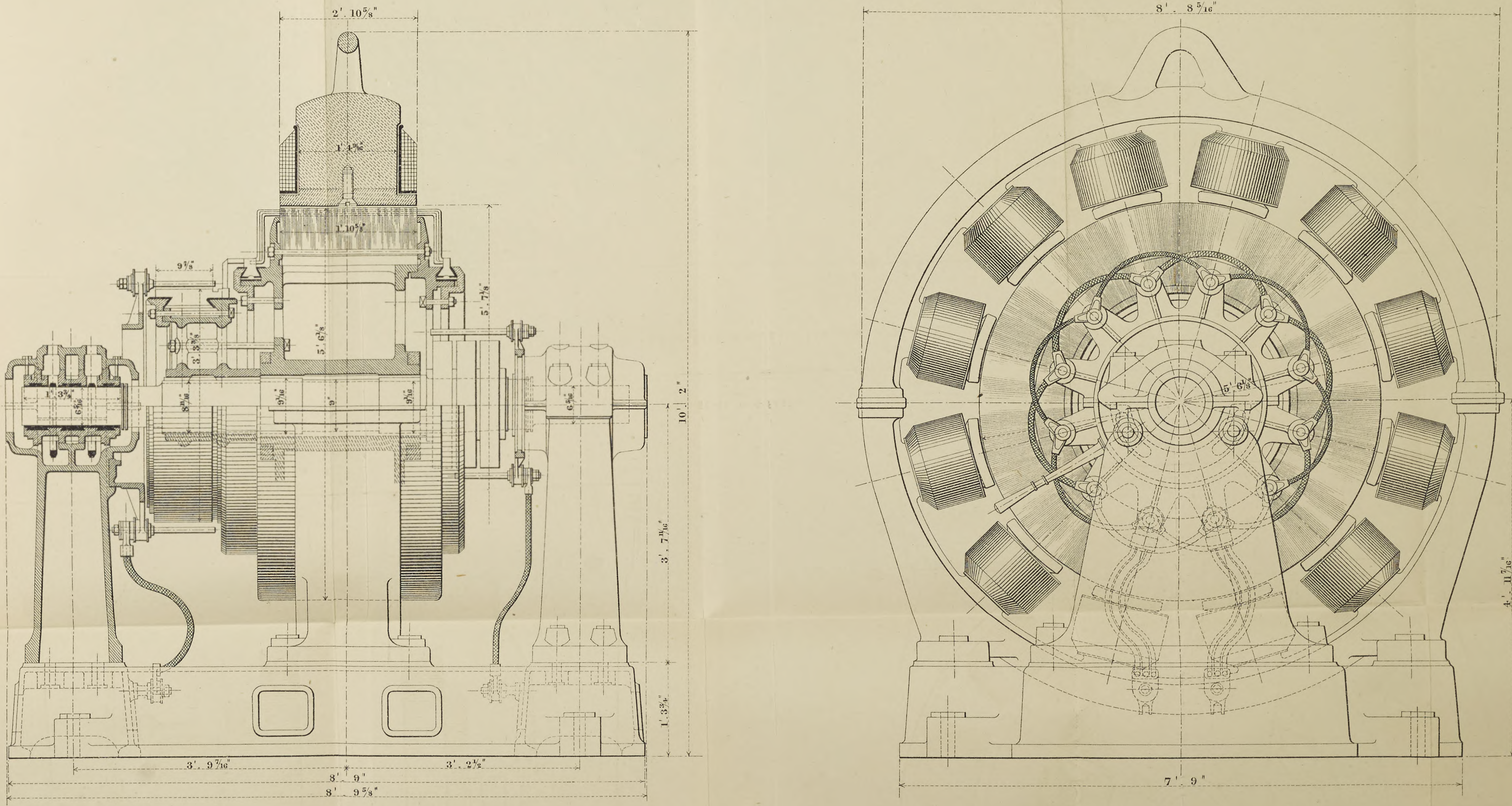
From results obtained over a period of one year the efficiency of working under lighting conditions may be taken as 74 per cent., and, from the few figures I have, the efficiency under traction conditions is 84 per cent.

I have found great difficulty in obtaining reliable figures as to the connection between the cost of coal, oil, water, stores, and repairs, and plant load factor. I have, through the courtesy of the engineer of an electrolytic works, obtained the figure of ·21d. per kw.-h. for the above items on a load factor of close on 100 per cent. I have weighed the coal to one boiler operating a single engine driving the traction load over sixteen hours, and, taking a low figure for the cost of oil and repairs at my station, I obtained the figure of ·3d. per unit for a load factor of 43 per cent., the engine being of 300 I.H.P., gave a fair load for a 30 ft. × 8 ft. Lancashire boiler using superheated steam. I obtained a third point on the curve by calculation from this test, allowing for the coal used in banking

450-500 Kilowatt Three-Phase Rotary Converter.

SPEED 250 R.P.M.— FREQUENCY 25 CYCLES — VOLTS 330-550.

Mess^rs Kolben & C^o Prague.



SCALE OF 4 FEET.

Inches 0 3 6 9 1 2 3 4 *Feet.*

A. C. EBORALL.

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

and in keeping the steam pressure at not less than 80 lbs., the working pressure being 160 lbs. The load factor is arrived at by assuming that the engine and boiler could give 200 kw. steadily. I shall be very much gratified if the discussion throws further light on this question, and enables me to correct or confirm the curve Fig. 18 plotted from the above figures.

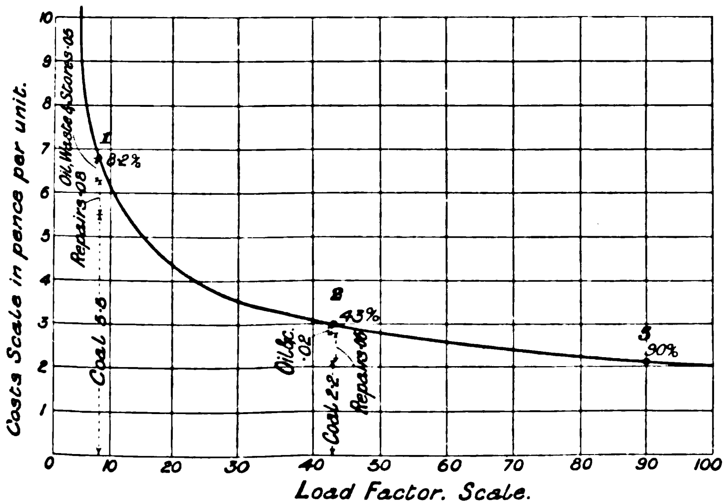


FIG. 18.—Load Factor and Costs.

Figures worked on basis of Lancashire coal at 9s. per ton. Load factor for points 1 and 2 = $\frac{\text{Units generated}}{200 \times 24}$. Point 2 is taken from a coal-test over 48 hours with a Lancashire boiler, 8 ft. dia., 30 ft. long, steam at a pressure of 150 lbs. per sq. in. superheated. Compound condensing engine 300 I.H.P. Coal used, 18,700 lbs. Units generated, 4,225. Total coal per unit, 4·44 lbs. Coal used in banking fires, 560 lbs. Point 1 estimated from this test; Point 3 from electrolytic works. The oil and stores and repairs are approximate.

It appears to me to be a matter of some difficulty to properly define the term load factor in this connection. Taking a single engine and boiler working at or near full load for a given number of hours, hours per day might be plotted on the horizontal line in Fig. 18 instead of load factor. The ratio between time of working and costs would then depend chiefly on the length of steam pipes which it is required to keep hot when the engine is standing. But the case might be considered where the engine and boiler are working continuously but at various loads, the curve would then represent the efficiency of engine and boiler at

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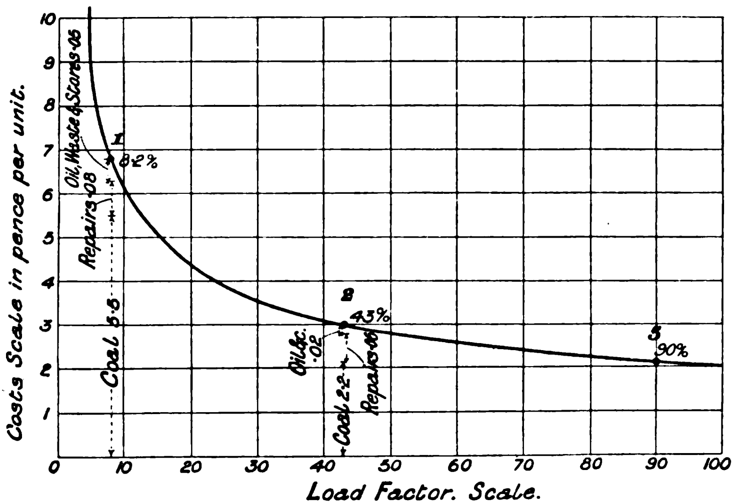

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these loads. With several engines and boilers the question becomes more complicated and I find myself unable to come to any general conclusion, and I submit the curve for what it may be worth.

With regard to the arrangement of batteries, the present tendency to connect all the cells together by burning the lugs of the plates in each cell is undoubtedly excellent practice. The shorter and stouter these lugs are made the better will be the self-regulation of the battery. Cells of stout lead, or of wood solidly put together and lined with lead, are preferable to glass boxes on light wood trays. It is of great importance that the positive and negative plates should be designed to wear equally; if one set of plates have much greater capacity than the other the weaker ones will wear out first, causing greater expense for renewals. Watt-hour meters for measuring the charge and discharge should form part of the equipment of all batteries; even daily charging and discharging are essential to the life of the plates, and if the daily input for a lighting battery is 25 per cent. more than the output, weekly readings of the specific gravity will show if the charge is right.

The energy efficiency obtained of 74 per cent. on the lighting battery is certainly due, in part at least, to the great ease of operating attained by the methods described.

The increased efficiency observed when the battery is worked as I have described, on an intermittent load, is interesting. It appears to be due to the fact that the discharges are often of such short duration that the increased pressure due to the gas effect is utilised on these discharges. The fact that the battery alone "floating" on the line operates best when the working pressure of each cell is taken at about 2·08 volts seems to confirm this view.

In conclusion I must apologise for the somewhat tentative way in which I have put forward my views; my excuse is that there are so many variables in considering battery working that it is not easy to find a starting-point from which to calculate. I have to thank Messrs. Elliott Brothers and the British Thomson-Houston Company for lending me several instruments, and my assistants, Messrs. Hollingsworth, Eccles, and Carter for helping me with the experimental work.

APPENDIX.

COMPLETE FIGURES RELATING TO AN ELECTRIC POWER STATION DRIVING A TRAMWAY AND GENERAL SUPPLY LOAD.

The figures relate to the period from March 31, 1900, to March 31, 1901.

		April to June.	July to Sept.	Oct. to Dec.	Jan. to March.	Year's Total.
Units Gener.	Lighting	58,938	64,350	122,924	124,907	371,119
	Traction	120,477	144,562	182,058	194,662	641,759
	Total	179,415	208,912	304,982	319,569	1,012,878
Units Sold	Lighting	47,620	53,845	102,410	105,382	309,257
	Traction	118,407	132,041	168,008	183,229	601,685
	Total	166,027	185,886	270,418	288,611	910,942
Batteries (1)	Charge	27,110	31,640	30,920	32,493	122,163
	Discharge	19,680	24,120	22,270	24,810	90,880
(2	Charge	—	—	Mar. 2nd to 31st only.	10,517	—
	Discharge	—	—		8,560	—
Booster Motor Units		From Aug. 22nd only.	2,660	6,194	5,720	14,574
		kw.	kw.	kw.	kw.	kw.
Max Load on Feeders	Lighting	180	216	278	250	278
	Traction	307	344	402	466	466
	Combined	482	560	638	675	675
Max. Load on Plant	Lighting	194	195	292	220	292
	Traction	206	302	212	255	302
	Combined	390	470	504	466	504
Plant Hours	Lighting	670	614	1,304	1,391	3,988
	Traction	1,455	1,418	1,410	1,451	5,734
	Combined	1,455	1,418	1,410	1,451	5,734
Load Factors	Lighting	12·1	11·8	17	19·4	12·7
	Traction	17·5	17·8	19·0	18·0	14·7
	Combined	15·9	15·1	19·4	19·5	15·4
Plant Load Factors	Lighting	45	53	32	41	32
	Traction	41	33	60	52	37
	Combined	31	31	43	46	35
Lighting	*Sold* / Gener.	80·8%	83·6%	83·3%	84·3 %	83·3 %
	Charge / Gener.	46·0 „	49·1 „	25·1 „	26·0 „	33 „
	Disch. / Sold	41·3 „	44·8 „	21·7 „	23·6 „	29·4 „
	Disch. / Charge	72·6 „	76·2 „	72·0 „	76·3 „	74·4 „
Traction	*Sold* / Gener.	98·3 „	91·3 „	92·3 „	94·1 „	93·7 „
	Booster / Gener.	—	—	--	2·94 „	2·94 „
	Charge / Gener.	—	—	From Mar. 2nd to Mar. 31st only.	16·02 „	—
	Disch. / Sold	—	—		14·0 „	—
	Disch. / Charge	—	—		81·4 „	—

The tramway system was very rapidly extended throughout the year, as is shown by the figures, the consequence is that the load factor over the whole year is lower than will be the case next year, when less new work will be done; the load factors for the quarters give a more true idea of the correct figures.

The boilers under steam at any time, were two Babcock boilers fired with refuse burnt in a Destructor, and two 30 feet × 8 feet Lancashire boilers, say the equivalent of three 30 feet × 8 feet Lancashire boilers.

TABLE II.

SHOWING CAPACITY OF BATTERY AND PLANT IN SOME DIRECT CURRENT STATIONS.

	Total Capacity in kw.		Ratio of Battery to Steam Plant in kw.
	Plant.	Battery at 3-hour Rate.	
Aberdeen	1,620	260	·16
Sunderland	1,880	60	·03
Norwich	1,664	120	·07
Notting Hill	660	100	·15
Oswestry	173	40	·23
Wolverhampton	1,440	220	·15
Manchester	7,250	240	·03
Lincoln	600	85	·14
Chester	1,000	30	·03
Charing Cross	4,900	800	·16
Chelsea	3,100	190	·06
Stockport	460	250	·54
Whitehaven	210	55	·26
Canterbury	300	150	·5
Leyton	1,260	200	·15
Hove...	1,200	90	·07
Barrow	525	40	·07
Halifax	1,900	200	·1
Nelson	116	88	·75
St. Helens	950	230	·24
Northwich	194	66	·34
Leith	640	115	·18
Llandudno	400	60	·15
Hull	3,900	300	·07
Bradford	3,569	270	·07
Burnley	822	120	·14
Shrewsbury	540	60	·11
Bury	760	70	·09
Kensington	1,000	157	·157
Edinburgh	9,697	460	·048
Dewsbury	485	85	·175
Southampton	730	250	·34
Belfast	2,200	200	·09
Harrow	350	70	·2
Stafford	198	140	·7
Nottingham	2,569	30	·01
Blackburn	2,127	75	·03
Glasgow	10,848	468	·04
Guildford	200	66	·33
Dundee	1,283	248	·19

Mr. Shoolbred.

Mr. J. N. SHOOLBRED: The subject matter of the paper is one which is of considerable interest, and it is one which is most satisfactory to those who, like myself, for many years past, have advocated the use of batteries in central stations. Eight or ten years ago their use was very much disputed indeed. It was considered that the batteries themselves were so expensive that economy could not result from their use. At present, scarcely a station for lighting purposes, at all events with continuous current, is without batteries; and now their use with tramways is expected to give still further important results, and they are being largely employed for this purpose. The author of the paper must be congratulated on the use he has made of his batteries at St. Helen's, particularly with tramways; as well upon the application of the interesting booster which he has described. That reversible booster is one way of treating the variations of the load, and the balancing of the inequalities. Personally, I have found it convenient, and I am not alone in doing so, to treat the matters in another way. Before accepting the "reversible booster" I should prefer to look, amongst other points, into the relative question of the economy and the simplicity of the machinery in both methods. The reversible booster, which has been explained to us, includes several moving parts, the booster, the exciter, and the motor, all of which have to be regulated. I think there is great advantage in using, with the three-wire system, dynamo machines working at "half pressure," which can be used as balancers on either side. They can also be used for a variety of purposes, such as charging a "half-pressure" battery, which is also available for "balancing," either with or apart from the dynamo. The results thus given are very convenient indeed in the regulation of the station. Nevertheless, I shall be very glad to look into this quesion of the reversible booster, as it certainly presents advantages, if only in the simplification of the battery regulating leads, which cannot be ignored.

The author, referring to Table II. given in the Appendix, says that he has endeavoured to obtain a report from various stations as to the relative capacity of the battery and of the generating plant, and tried to form a ratio between the two, and that he finds a difficulty in explaining exactly the results. I have looked very carefully into that table, and I quite agree with him—taking the figures as they stand. For instance, two stations that I laid down are included in the table: Bradford, with a ratio of 0·07, and working for eleven years; and Stockport, with a ratio of 0·54, and only two years' running. Yet, in both places, the ratio at the outset (by far the most important time) was about 0·60 per cent. of the generating plant. Again, not sufficient distinction is made between the application of batteries to lighting and their application to trams. In my opinion, the two ought to be kept perfectly distinct from one another, if only for this reason. In providing a supply of electricity for lighting purposes, the relative value of the batteries, and of the generators as current-providers, may be looked upon as a sort of mathematical series. At the commencement, when the load is small, it is the batteries which are of the greatest value. But their value diminishes as the load increases, and that of the

Mr. Shoolbred.

generator is correspondingly increased. Still the battery, even though of diminished importance on the score of a supply-provider, never ceases to be an *absolute necessity* in a station, for many other reasons, too numerous to discuss here. Thus, in lighting stations, to quote the ratio alone between the plant and the batteries (a figure which is always varying with the age of the station) gives no idea of the actual value of the battery in the working of the station, especially if three-wire arrangements are in use. Again, in Table II. no distinction is made, as to, whether and to what extent the battery is used for lighting, or for tram purposes. Yet this distinction is most important. For, while with lighting, as has just been pointed out, the relative value of the battery, as a current-provider, diminishes as the supply increases, with the tram-supply this is not the case—the ratio remains much more constant. As all of these matters should be taken into consideration in the table, and they are somewhat difficult, perhaps, to distinguish, it is not surprising that the results, as they at present appear in that table, are somewhat difficult to understand. The object, I take it, of the batteries in tram-work is to take off the excessive load-peaks that occur, and which are due to starting stresses, and thus to leave a certain broad and more regular quantity, which represents the body of the load, to be dealt with by the dynamos directly. The relief thus afforded to the dynamos would seem to be the great value and advantage of the battery in tram-work. The duty expected from the battery therefore bears a somewhat direct proportion to the total load. As the load increases, the extra proportion of battery reserve to take the peak may likewise increase; but it is a totally different requirement from that of lighting. The author refers to the grading of the generating plant. This has been acknowledged, from the commencement of electric lighting central stations, to be a matter of very great importance. It is about ten years ago, and in this room, that the late Mr. Willans, when discussing one of the earliest installations, that of the Bradford Corporation—as I daresay Colonel Crompton, who is present, will remember—strongly urged the advisability of not having too large units to begin with, and not to have more than two or three types of dynamos in each station, reducing thereby the number of types of spares. I quite agree, therefore, with the author as to the immense importance of simplicity in what he terms the grading of the generators. The part that batteries play in equalising and assisting that grading by filling up the load-gap, between the economic working percentage load of one dynamo and that of the next dynamo to be put on, or *vice versâ*, so as to enable the dynamos to work as near as possible at full load, is a part that persons, who have not very closely followed the working of a continuous-current lighting station, can hardly appreciate. This use of the battery has a very great economical bearing on the working of the station; and it is one which is only beginning to be realised. Great as has been the advantage from the use of the storage battery in lighting stations, there is, in my opinion, an even larger future in connection with tramways. The author is particularly deserving of our best thanks for the interesting series of diagrams which he has brought before us; and I think we ought not to omit, also, to record our thanks to Mr. Grindle for the

very valuable and kindred paper, and diagrams illustrating it, that a short time ago he brought before the Manchester section of this Institution. These papers have pointed out to many, who have not had the opportunity of seeing them, the use to which batteries are put on the Swiss tramways, particularly on the Zurich and Lucerne trams, and on others on the Continent. Mr. Shoolbred.

The author has also referred to another point, namely, the life of a battery. The life of a battery, as he very properly says, depends not merely upon the use which is being made of it, but also, and even more, upon the constant and daily attention, so as to remedy at once any incipient defects. Several instances have come under my notice where batteries, which have remained in good order for several years, under such inspection, but which have, once that supervision was removed, very quickly come to an untimely end. In conclusion, I can only add my thanks to the author for having brought this very interesting and most useful communication before the Institution.

Mr. G. A. GRINDLE: I do not think I can say much, except to congratulate Mr. Highfield upon the very lucid and able paper he has had the pleasure of laying before us this evening. For many years past we have all felt the necessity of some means of dealing with the question of the regulation of batteries, and the only means which has hitherto been open, namely, that of regulating cells, has been extremely unsatisfactory; not only unsatisfactory, but at the same time very much to the detriment of the battery. I speak from experience. In this system which Mr. Highfield has, I may almost say introduced, nearly all those difficulties have vanished, and from actual experience I can say that we have one of the most perfect means of employing a battery for lighting or tram work that has yet been designed. The system he has described to you is most workable; we have employed it now in several places, and I have had it under my own control with the most satisfactory results. Mr. Grindle.

The PRESIDENT: Can you give us a little information about the maintenance of cells. The President.

Mr. GRINDLE: I think that this system assists the question of maintenance more than anything else. The working of the booster in this way puts the cells in the most advantageous position. Nothing, I think, is more detrimental to a battery than to run it down, and under the usual methods of working this unfortunately perpetually occurs. By the employment of a booster this difficulty is overcome; the battery is practically always kept working on top of the curve. The moment a heavy discharge goes out it is almost immediately replaced, with the result that the battery works under the most satisfactory conditions, and consequently the maintenance is very much assisted. Mr. Grindle.

Mr. W. H. PATCHELL: I think we must all congratulate Mr. Highfield on the very ingenious method of doing away with regulator cells that he has brought before us. I have been working with boosters for the last five or six years. I first used them to charge a 100-volt battery with a 100-volt dynamo, as many people are doing. But while doing that, and when arranging to increase the plant, it occurred to me that one might work a booster with a reverse field, so that we could use it Mr. Patchell.

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Mr. Patchell.

either for plus or minus, and get practically the same results which Mr. Highfield is getting. I was working in the early days with a double-wound armature, which I found was not quite convenient, and gave it up. I now have simply a motor generator, and use 1,000-ampere units. Of course they require hand regulating, and we cannot work them in the way Mr. Highfield does. I have some of the motors driven from 1,000 volts high tension. Those, of course, can only be run when the plant outside the district which supplies the high tension into the district is run. Others I have working off the outers of the ordinary three-wire system; and these, of course, are available at any time, day or night. I can work either one, I find, with the greatest convenience, and so do without regulator cells, which always give trouble. I quite appreciate what Mr. Grindle says, and that he, as a maker, would be very glad if we would all do away with them. If he sorted out his correspondence into two bundles, and put the complaints of battery regulator cells in one bundle, and complaints of other battery failures in the other B. bundle, I think he would have a very small B. bundle. At any rate, we practically do not know what difficulties are. All the difficulties we had with the old battery are done away with now that we have done away with the regulator cells. Another point that led me to do away with regulator cells was the very small value obtained from them compared with the rest of the battery. Supposing 60 cells are required to work a 100-volt circuit: 50 will do just as well if you have a booster, and in big cells you will find that the saving of the cost of the extra ten cells, with their leads, very far outweighs the cost of the booster and the small switchboard that you require to work it, so that it is a far cheaper method in prime cost. If you are discussing battery maintenance you have only to discuss maintenance on 50 cells instead of 60, and there you get another score, so that the saving is a cumulative one. I am sorry I cannot put any records before you as to efficiency, because I did not know of the paper till last night, and I only had it in my hands this evening, but I think Mr. Highfield has not overstated the efficiency of the battery. There is not very much difference if the efficiency does come out at 75 per cent., so long as you can save it on the coal, which you can over and over again by a steady load. Our own peak for one figure that I have in my mind was 26 per cent., and the plant that was running had to run six hours a day only, and only earned 4 per cent. of the money. That is very bad for the plant. You do not get your money back on the plant, and then for the other eighteen hours of the day we had the stand-by loss on that same plant, which we could cut altogether by using batteries. I think the early battery stations are prejudiced by not having had good cells to work with. The plates were put too close together, and in a good many cases a short circuit was obtained almost before they started. The battery station at Chelsea, which was to teach us so much, is about at the bottom of the list. That is due to prejudice. If they would start again with an up-to-date battery with ½ inch between the plates they would level their curve, and improve their results.

Mr. Wordingham.

Mr. C. H. WORDINGHAM: I have listened to Mr. Highfield's abstract of his paper, and must certainly very heartily congratulate him on the

invention which he has described. It appears to me that it will have very far-reaching influences on the industry, both for lighting and, especially, for traction. I myself have always thought that one of the greatest difficulties in the use of a battery was to know when to charge it, because it is at all times so very useful. You want to use it twenty-four hours a day, and practically that is what Mr. Highfield does, just squeezing in the charge at odd moments. It is impossible to criticise the details of the working without having carefully studied the paper, but it really seems as if all the difficulties had been solved by the author. Mr. Wordingham.

Mr. H. M. SAYERS: Mr. Highfield's paper attracted me considerably since I saw what he had been attempting and what he has succeeded in doing. It attracted me because during the last two or three years I have at odd times given considerable attention to the problem, and although I believe I found paper solutions, I have not found a practical working solution. Mr. Highfield apparently has done so. I have not been able yet to get through his booster and exciter diagram, and see exactly how it works. The only criticism about that which I should like to make is, that probably a series-wound machine on the generator side of the booster might simplify matters a little. The particular problem that I have had in my mind was supplying lighting from batteries in combined stations for traction and lighting purposes, and I particularly wished to be able to charge my lighting batteries from the traction sets during the time when the load permitted. This I have succeeded in doing. As regards the charging, I have succeeded in doing that without abusing the regulating cells, and the result upon the load-factor of the traction station and the result upon the costs has been exceedingly satisfactory. The costs per unit generated in the station have been knocked down fully ½d. since that plant has been in operation. For tramway purposes some of us have thought that the battery had not a great deal of application, except in sub-stations, but I must say that my experience has brought me to the opinion that in many cases tramway plants would be greatly advantaged by a battery. The method here shown by which the polarity of the regulating booster is varied in accordance with the load, and the regulating cells are entirely cut out, seems to make it a practical thing. On tramways where only a small number of cars are in operation it is well known that the variations in the load are very large and very uncertain. In one case with which I am personally acquainted we get peaks of 380 amperes with an average load of only 90 amperes, so that whilst a 100-kilowatt set is underloaded on the average, one wants 200-kilowatt sets for a few seconds at a time. Of course we do not give it. We run the 100-kilowatt set, and the voltage and the speed drop. That is not a very satisfactory state of things. A battery on Mr. Highfield's plan would undoubtedly help us there. In another case an average load of 70 amperes has peaks in it of 240 amperes. The curious thing about these lines with a small number of cars is, that the peaks are quite periodical. It is very natural, when you come to consider it, and you find that the connection between the periodicity peaks and the time-table is a perfectly simple one. I would like to point out that on lines Mr. H. M. Sayers.

Mr. H.M. Sayers.

which are laid with single tracks with turnouts, multiplication of the number of cars never can bring the peaks down to a very large extent, because the very method of working involves the simultaneous starting of two cars at each starting place; and if you will think it out it involves the nearly simultaneous starting of a considerable number of pairs of cars at a considerable number of passing places. Obviously the best arrangement is to have the passing places evenly spaced, so that the cars take even times to run from one passing place to another. Under those conditions every other passing place has a pair of cars on it starting at a particular moment. Consequently the multiplication of the number of cars does not cut down your peaks to a very large extent, unless you are working a number of branch lines with different services on them. So that for small stations, and for stations of pretty fair size, it would appear that this battery arrangement has a large field of usefulness. We certainly would like to have a few figures, which of course can only be supplied from experience, as to the efficiency and economy of working. It does appear to me that it is very promising. With regard to first cost, we are told in the paper that for traction conditions the batteries do not cost very much more than the steam plant for the same output. I have not been able to see how that is equated; perhaps it is a question of the way in which the output is taken. My experience has been that batteries cost a good deal more than the steam plant, leaving buildings out of account. With regard to the figures of efficiency, 84 per cent. is, of course, very much more than we have experienced from battery use under lighting conditions, and it appears to show that the extra voltage due to the pòlarisation or to the gassing is utilised to considerable advantage, so that the discharge battery under these conditions is not a discharge from 2 volts down to 1·8, but a discharge from 2·2 volts down to 2 volts, or something of that sort, so that the voltage factor of the discharge is very much better in relation to the voltage factor of the charge than under more ordinary conditions. The exact figures of the efficiency would be very useful to us. I trust Mr. Highfield will be good enough to say if his 84 per cent. includes as input the power taken to run the booster. Mr. Highfield talks about load factor, and asks for some assistance in a good definition of load factor. I have found that the most useful load factor (among the many things called load factors) to the station engineer is the "running plant load factor," that is to say, the relation between the actual output of a station and the output which would have been given at full load by the plant actually run during the time it was actually running. This figure and the cost of generation follow each other inversely in a very close way. When I have been in charge of running stations I have directed my energies to keeping that running plant load factor high, and the result has been very satisfactory.

Professor Wilson.

Professor E. WILSON: I should like to congratulate Mr. Highfield on his excellent paper, first because he is an old King's College student, secondly because he has brought forward a very ingenious invention, and thirdly because he has put that invention to a practical test, and has made it a success. I think it is in connection with electrical traction, where the fluctuations of the load are severe and

Professor Wilson.

sudden, that this automatic reversible booster is of great value. In electric lighting this does not appear to be so important, but in connection with electric traction it is of very great importance. Mr. Highfield has shown that on small traction schemes at any rate this reversible booster can effect considerable economy. Other systems have been devised with the object of effecting what Mr. Highfield has put before us, and one of these systems I should like to point out to you. It is by Messrs. Siemens & Halske, of Berlin, and is shown in Fig. B on the diagram. Fig. A gives Mr. Highfield's system, for the purpose of

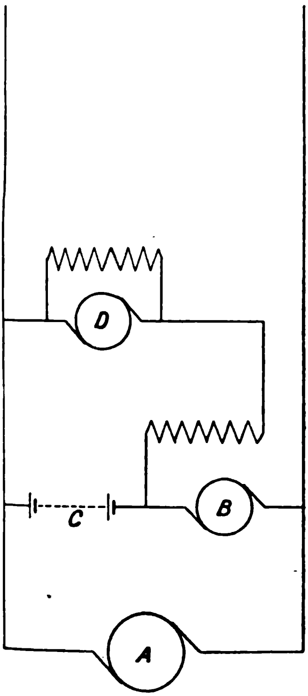

FIG. A.

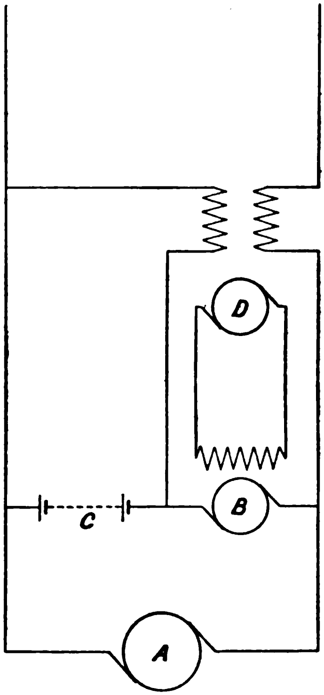

FIG. B.

comparison. In each, A is the generator, B is the booster, C is the battery, and D is the exciter. In Mr. Highfield's case the exciter D gives a constant potential difference; whether it is a motor or a generator, its E.M.F. is practically unaffected by the variations of the current flowing though the armature. The magnitude and direction of the exciting current of the booster B is determined by the difference of potential difference between the exciter D and the battery C. Obviously it will be positive or negative according as the battery has higher or lower potential difference than the exciter. In the Siemens & Halske arrangement the exciting coil of the booster is connected to the terminals of the exciter, the excitation of which is the difference of the current turns due to two coils wound upon its magnet. One coil is

Professor Wilson.

placed in parallel with the battery, the other coil is placed in series with the conductor which goes to the line. It is obvious by suitably adjusting the number of turns that, according to the potential difference of the battery and the current in the line, the net ampere-turns upon this magnet will be positive or negative, as the case may be—that is to say, the exciter gives a positive or negative current through the exciting coil of the booster, and the potential difference of the booster is positive or negative accordingly. Whether this system has ever been put into actual practice or not I do not know, but it is of interest. One advantage of Mr. Highfield's arrangement is that you have simply the reversal of the booster potential difference, whereas in Siemens & Halske you have to reverse on two commutators. When one starts designing an automatic reversible booster for the purpose set forth, one naturally considers the differential winding of the booster itself. If the figures are carefully gone into, it is found that the amount of copper required to be put upon the booster is excessive. I do not know if the Siemens & Halske arrangement, of using a small exciter and differential coils upon it, leads to more economical working. There are other systems, too, which time does not permit one to describe. Entz in America has worked at automatic reversible boosters, and I have an interest in one. With regard to regulating cells, I think they are a thing of the past, except, perhaps, in the case of small private installations. After having had considerable experience with the automatic adjustment of charge and discharge switches, I feel sure that it is impossible by this means to properly cope with the fluctuations met with in traction work. It is now generally recognised that the reversible booster is the proper thing to employ, both for traction and for lighting, but it is in the former that it should be automatic.

Colonel Crompton.

Colonel R. E. CROMPTON: I will take first a point which I did not intend to allude to, but it follows Professor Wilson's remarks. He has mentioned that in America, as in other places, reversible boosters have been used. Unless I am very much mistaken, Mr. Chamen, when he was with my firm about eight years ago, worked out at my request an arrangement almost if not quite identical with that which has been so ably put before us to-night by Mr. Highfield, and we took out a patent for it. We sold our rights for its use in America, and I believe it has been used there. This does not for one moment detract from the admiration we feel for Mr. Highfield's skill and ingenuity in adapting what is, as far as I understand it, practically the same invention for his station.

I think I have had nearly twenty years' experience with accumulators, but, although I was very active in experimenting some years ago, I have not had so much work with them of late years, so that I am getting rather rusty on recent practice. As some of you will remember, about twelve or fourteen years ago, the subject of the pros and cons of using accumulators, and my own attempts to answer some of the questions which have been put again before you by Mr. Highfield to-night, used to draw large meetings. I only wish that I had had such a good man as Mr. Highfield on my side in those stirring times. I assure you in those days we stood up for batteries working in parallel with our

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generators. When we talked about their helping us over the peak of the load and helping to fill up the steps between each successive added generator, we were listened to with a great deal of incredulity by the larger parts of our audiences. I am glad to see that things are different now. There is no doubt that Mr. Highfield is right. I will tell you, gentlemen, one very important reason why accumulators have not been used to a far greater extent than they are used, and ought to be used, is because the men who managed them in the past differed so greatly in their care and knowledge of them. The management of a battery of accumulators is a thing by itself; every man is not built that way. A great many fellows are splendid engineers with their boilers, steam and dynamo machinery, but accumulators are too much for them, and in all those stations the batteries have either been a failure, frequently breaking down and giving trouble, or by high repairs have been a financial failure—that is to say, the repairs and maintenance have been so heavy as not to warrant further extension and use. On the other hand, we have men who, like Mr. Highfield, have gone into the question, have seen the weak points, have used their brains, and the result has been what we have heard to-night, upon which I most heartily congratulate him. I think Mr. Patchell was a little hard on us older hands when he talked about the ignorance of early manufacturers. They who laboured in the early days making and developing the accumulators which you now benefit by had a hard and difficult job; experience only came in very slowly. Mr. Patchell talks about accumulators ten years ago not being properly spaced. I think it is nearly fifteen years ago since I introduced ⅜ in. spacing. That, no doubt, was a very great improvement, which made the maintenance of accumulators cost very much less than it used to. I quite agree with Mr. Highfield and Mr. Patchell that the chief wear and tear has always to be debited to the regulating cells, and it was that which made me call upon Mr. Chamen to invent to order some apparatus—a reversible booster, in fact—to take the place of the regulating cells; and he did it satisfactorily. I quite agree with Mr. Highfield that a very fair mean cost of installing accumulators to be discharged at a three-hour rate would be £35 a kilowatt, and I think that with the right men it will be found to pay to instal at this cost a much larger proportion of accumulators than is generally the case. I should agree with him even if the rate of depreciation was much higher than the figure he gives. For many years I calculated for a rate of depreciation being charged against the accumulators of the Kensington Company at 14½ per cent. per annum—that is to say, whatever their annual upkeep did cost was deducted from the sum yielded by 14½ per cent. on their first cost, and the balance, if any, was carried forward to a fund. For many years there were accumulations in that fund, but afterwards, when the station grew larger, the batteries were overworked in the manner Mr. Highfield has stated. Then repairs came higher, and that 14½ per cent. figure was insufficient. Some speakers have doubted that such high efficiency percentages as 84 per cent. can be obtained. I am only speaking from memory, but I think that in the station engineer's books of the Company I have just mentioned—the Kensington Company—for many years the

Professor Wilson.

placed in parallel with the battery, the other coil is placed in series with the conductor which goes to the line. It is obvious by suitably adjusting the number of turns that, according to the potential difference of the battery and the current in the line, the net ampere-turns upon this magnet will be positive or negative, as the case may be—that is to say, the exciter gives a positive or negative current through the exciting coil of the booster, and the potential difference of the booster is positive or negative accordingly. Whether this system has ever been put into actual practice or not I do not know, but it is of interest. One advantage of Mr. Highfield's arrangement is that you have simply the reversal of the booster potential difference, whereas in Siemens & Halske you have to reverse on two commutators. When one starts designing an automatic reversible booster for the purpose set forth, one naturally considers the differential winding of the booster itself. If the figures are carefully gone into, it is found that the amount of copper required to be put upon the booster is excessive. I do not know if the Siemens & Halske arrangement, of using a small exciter and differential coils upon it, leads to more economical working. There are other systems, too, which time does not permit one to describe. Entz in America has worked at automatic reversible boosters, and I have an interest in one. With regard to regulating cells, I think they are a thing of the past, except, perhaps, in the case of small private installations. After having had considerable experience with the automatic adjustment of charge and discharge switches, I feel sure that it is impossible by this means to properly cope with the fluctuations met with in traction work. It is now generally recognised that the reversible booster is the proper thing to employ, both for traction and for lighting, but it is in the former that it should be automatic.

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efficiencies were got out every month for the Board meetings, and they used, to vary between 81 and 84 per cent. for many months together, if not for years. I should mention that as regards Chamen's invention, we called it an Updown Dynamo. I wish heartily to congratulate the author on having dealt so ably with such an interesting subject, and a subject, what is more, which deserves well dealing with.

Mr. Trotter.

Mr. A. P. TROTTER: I have a very few words to say on this paper. Mr. Highfield is one of those Midland engineers who come too seldom to London. He has not even told you where he comes from. He comes from St. Helen's, one of those towns in which the Corporation does its lighting and supplies current to the Company which runs the trams, and also one of those very few places where there is a destructor which is actually earning its food and doing really good work. I have watched this booster running several times. Of all the switchboards I have ever seen I know none more interesting than those at such stations as St. Helen's and Birkenhead, where the Highfield boosters are used. To see the ammeters and voltmeters and recording instruments following each other, and to see this little machine running round, apparently doing all the thinking and keeping the main ammeter needle marvellously steady, is remarkable. In the battery room there is simply a row of batteries, and a main conductor coming in at one end and going out of the other: there is none of that forest of connections that you are so familiar with. To watch the battery is interesting, because if you stand by it you can hear the load coming on and off, just like the patter of rain. There is a little buzz as the charge comes on, and it is silent again when the current has been taken out of it. One has a chance of seing on these records, without a roundabout calculation by a meter, what the average amperes are, for in a traction works station no one knows exactly what is the average output. I must say that the average current seems to be extraordinarily low. If I remember rightly, there are some hills in St. Helen's, but on Fig. 11 you will see that dotted line which seems to be about 240 amperes for 20 cars, and on Fig. 12 300 amperes for 25 cars, works out at about 12 amperes per car. In ordinary practice 20 amperes to 15 amperes is fairly good work; but in this case we find the low figure 12, and I would like to ask the author if he could tell us whether there are any special features in his line, or the size of the cars, which brings it down to that low figure.

Mr. W. B. Esson.

Mr. W. B. ESSON: I am glad Mr. Highfield has taken up the matter of the proportion of battery capacity to steam plant capacity, for though frequently, in discussion, this point has been referred to, ideas on the subject do not appear to have taken very definite shape. In Table II. of his Appendix, Mr. Highfield has lumped the stations together in a somewhat higgledy-piggeldy way, and it would appear from the figures that there is no sort of law governing the proportion. But if we re-arrange the stations in order of plant capacity, we see at once that the broad principle applies of large battery proportion for small stations, and small battery proportion for large stations. For stations under 500 k.w. capacity, the ratio of battery to steam plant appears to average 0·25; for those of from 500 k.w. to 1,500 k.w. about 0·125; above 1,500 and

up to 5,000 k.w., 0·100, and above 5,000 k.w., 0·04. There is, of course, considerable variation amongst the figures, but the above give the average and clearly indicate the law I have referred to. Now this is just what we would expect, as the battery occupies in a large installation a very different position to what it does in a small. In the latter, the battery forms, so to speak, an important and essential part of the generating plant, as it furnishes the supply for a considerable portion of each day, enabling the running machinery to be shut down during that period. But with the development of a station, there comes a time when it is less costly to run machinery continuously than to increase the battery power. The battery no longer acts as supply plant, and the reason for the proportion of battery capacity diminishing as the station gets larger is simply due to the fact that the battery is not increased at all, or increased in very small proportion to the increase of plant capacity. The proof of the pudding is in the eating, and after many years' experience the universal practice is for the battery power to shrink as the station grows. In this matter, Mr. Siemens was a truer prophet than Mr. Crompton, as he remarked several years ago—and I think in this very room—that accumulators were only of use for toy stations. With all deference to Mr. Highfield, a very good reason for the great diversity in practice is furnished by the process of station development. As larger sets are added in the station, the original sets serve for the light loads, and this grading of the units admits of the station being worked economically independently of the battery. Mr. W. B. Esson.

I note that Mr. Highfield does not propose to adopt for large power-stations shunt-wound dynamos combined with batteries in place of the usual plant, and in this I think he is quite right. After all, simplicity is the great thing to be aimed at. With regard to the efficiency of the battery given for one year, 74 per cent., Mr. Highfield might let us know if this is for the first year of the battery's life, or had it been working for some time prior to this twelvemonth?

Referring to the cost of generation as determined by the load factor, I do not think it is difficult to arrive at this. We see frequent reference to the want of economy resulting from running generators at ½-load, ¼-load, etc., but engineers, as a class, do not seem to have very definite ideas as to what the difference in steam consumption would be. Long ago, the late Mr. Willans showed that the steam consumption per hour of a direct-coupled generator might be expressed in the form:—

$$a + bW,$$

where a and b are coefficients depending upon the construction of the engine, and W the output in watts. From this you will observe that the total annual steam consumption is made up of two terms, the first dependent only on the number of hours for which the set is run, and the second depending only on the units generated and quite regardless of the hours run to produce them. When it is remembered that the quantity a is for a non-condensing engine about one-third of the total steam taken at full load, it will be seen how important it is to get from each set maximum number of units for a minimum number of hours running. The result works out something like this. Taking a 500 k.w. set, the steam consumption at full load might be taken at 33 lbs. per

Mr. W. B. Esson. k.w.h. = 16,500 lbs. which means that running round on light load, there is consumed every hour 5,500 lbs. of steam. Assume for the sake of argument that the cost of steam raising is *one penny* per 100 lbs. and we have the cost of running the set as :—

$$4s.\ 7d. + \cdot 22d. \times K.W.$$

That is to say, year in, year out, for every hour the set is running, you have a standing charge of four shillings and sevenpence to pay whether generating 5 or 500 units per hour, each unit costing, after this charge is paid, something under one farthing. When condensing, the standing charge would go down to 2s. 9d., but whatever the amount, there is no escape from its payment. A little arithmetic will show that while working non-condensing at full load, the total steam cost per unit is ·33d., at ⅔rds.-load it is ·38d., and at ⅓rd.-load it is ·54d.: assuming that the cost of fuel corresponds to 1d. for every 100 lbs. of water evaporated. This will show that it is not difficult to get at the cost of generation in terms of the load factor, though for a complete statement the behaviour of the boilers, steam pipes, etc., must also be taken into account. This simple approximate law for the generator enables us to see that the cost per unit depends largely on how the generators are loaded, and amongst other things teaches us that if we have to run a number of similar generators for a particular load, the manner in which the load is divided amongst them makes no difference to the cost per unit. With some fully loaded and others partially loaded, we have just the same result as if all were loaded equally. But cut out one machine, and so wipe out on its account some of the standing charges, and the cost per unit at once goes down.

We must all admit that Mr. Highfield's booster is a very ingeniously contrived apparatus, and he very clearly sets forth its object. It is required because of the great fluctuations of the battery E.M.F., on very rapid discharges and its function is to even up the battery characteristic, so that working in conjunction with a shunt dynamo, it discharges and takes charge in accordance with the demands of the plant. But that battery working will ever come into use for large plants is not at all likely. Mr. Highfield in such cases would confine batteries to substations, remarking that he does not think the central station the correct place for them. Might I go further and say that *they* are not the correct thing for a substation, or boosters either for that matter, which brings us back to the simplest of all methods of working, by compound wound generators, which is also the least costly in maintenance and supervision.

Mr. S. F. Walker. Mr. S. F. WALKER: I venture to think that the whole question turns upon the method of charging—that is the crux of the whole thing—and that what Mr. Highfield and others who have worked in this direction have done is that they have not only got rid of the regulating cells, but of a large portion of the work on the plates. I think Mr. Sayers has given us the key to the whole matter. You are working practically on the gas: you are getting your 2.2 down to 2, instead of taking it out of the charge, and are therefore getting a higher efficiency and a longer life.

Mr. Kilburn Scott.

Mr. E. KILBURN SCOTT (*communicated*): There is one application of the reversible booster which I think is most interesting, namely, for very heavy crane work for docks, wharves, etc. When comparing the power possibilities of an electric crane for dock work with its prototype

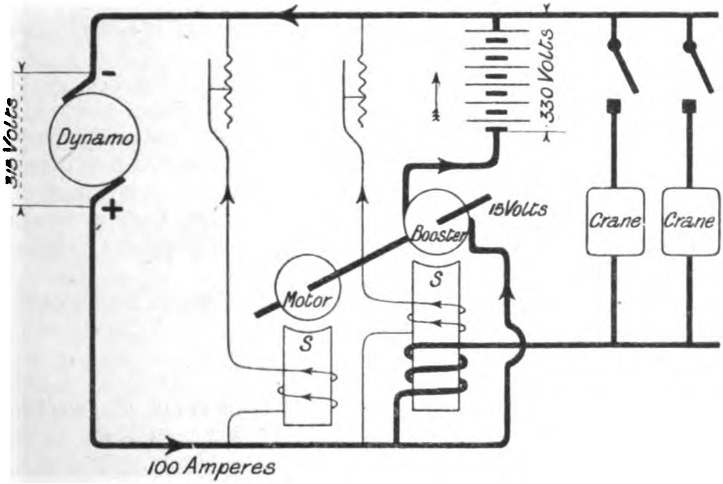

FIG C.—CHARGING CELLS. CRANES OUT OF CIRCUIT.

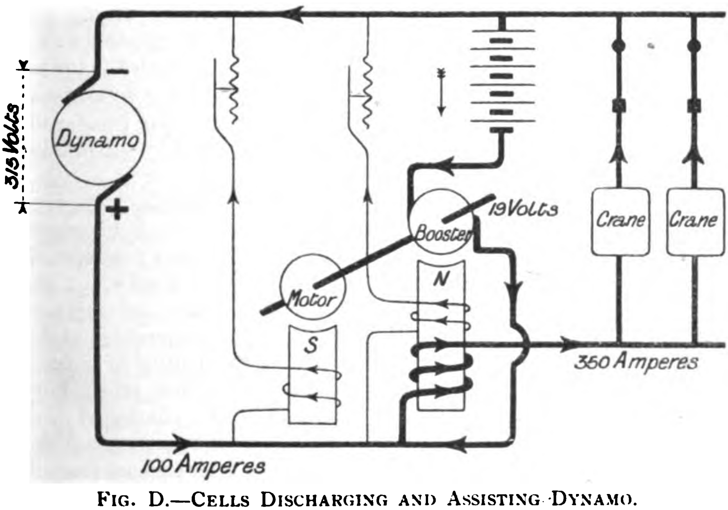

FIG. D.—CELLS DISCHARGING AND ASSISTING DYNAMO.

the hydraulic crane, there is this to be considered, that the hydraulic crane has always the pressure of water from the hydraulic accumulator to draw upon. On this account it is *necessary to work* large electrical cranes in conjunction with accumulators to make them at all comparable with hydraulic cranes. Now if an electric accumulator is used at all, it must be with the reversible booster, otherwise the cost is quite

Mr. Kilburn Scott.

prohibitive. About fifteen months ago I had to work out such an arrangement for some large cranes for a London Dock, and Figs. C and D show the arrangement adopted. There is a little extra expense on account of the series winding on the booster field, the commutator must also be large enough to carry the full discharge current, and in order that the polarity may reverse readily, it is well to work at a low density and use laminated iron poles.

It may be mentioned that the reversible booster has been used for some considerable time for working tramways in several towns on the Continent. The Remscheid tramways which the Union Company of Berlin equipped so long ago as 1892, was probably the first example, the reversible booster in this case being arranged on a modification of the Siemens and Halske device. See a paper by M. Ludwig Schröder on Electric Tramways with accumulators, read December 15, 1896, at a meeting of the *Elektrischer Verein.*

The Lisbon tramways are worked with a reversible booster, and so also are the following tramways in France :—

Paris Metropolitan Railway, Bercy.
" " " Étoile.
Paris Tramway to Epinay, and the Tramways of Fontainebleau, Armentières, Montpellier, Boulogne-sur-Mer, Orléans, Poitiers, Pau, and Toulon.

Mr. Booth.

Mr. W. H. Booth (*communicated*): The author is to be congratulated on his excellent paper and the manner in which he has put forward the points in favour of accumulators. There can be no doubt that a good battery, well cared for and not overstressed, ought to prove a very paying investment in small traction systems. The load-factor is the factor that dominates the position. The author's statements as to load-factors appear to be substantially accurate. So far as figures have been available by me the load-factor would appear to be determined by the number of cars at work upon a line, *i.e.*, at work in parallel.

Each car constitutes an element of disturbance. As regards current consumption, the load-curve is simply a series of numerous maxima interspersed with many zero peaks. For very few cars, there are also many points of zero when the only station load is that due to engine and generator friction, but there will be a less aggressive series of maxima. In fact, as the number of running cars increases so do the peaks and valleys diminish. No doubt, also, the nature of a line, the distances between loops and other factors have their effect, but the primary factor is the number of elements which are combined to make the full load. By observing many hundred cases in ordinary tramway work I have found that the load-factor within a field varying from three to forty cars at work may be taken as some multiple of the cube root of the average number of cars. That is to say, if the number of car-hours in any period of time—say twenty-eight days—be divided by the station-hours in the same period, the quotient will be the average number of cars working every hour. The cube root of this number multiplied by 10 to 12 will give the load-factor. Thus with 8 cars the load-factor will be 20 to 24, with 27 cars 30 to 36, with 64 cars 40 to 48. The formula is, of course, purely empirical, unless possibly the $\sqrt[3]{}$ represents some

correct basis; but it serves for the ordinary 18 to 20 hours' day of the ordinary tramway system with comparatively short periods of light load in the early morning and later at night, and it certainly fits with facts up to the range of small stations and would give a load-factor of 80 to 90 for a system of 500 cars run off one system of mains, *i.e.*, all electrically in parallel. Mr. Booth.

Small or large cars do not appreciably affect the result, which strengthens my opinion that load-factors are chiefly dependent upon the effect of numbers, though of course a single large car will have a higher maximum peak than one small car.

The difference is not appreciable on the maximum station curve. Approximately the fuel consumption of a traction station, per unit of output, will vary inversely as the load-factor, and it is here that the possibility of economy enters. Large stations with many running cars have fairly steady loads and much is not to be expected from them in economy due to accumulators. But in a small station with a load-factor of perhaps 16 per cent., there is a large margin for economy. In the small system, running only three or four cars, special occasions may demand the use of double or treble the cars, and the station plant of a small tramway is always most excessive and could be kept much smaller with a battery to help the holiday traffic. In a small tramway system with its paltry load-factor it is sheer waste to employ costly and large compound engines to work at a mean load of one-fourth their capacity with the idea that compound engines are economical. A compound engine cannot be overloaded beyond the maximum steam inlet of the H.P. cylinder. This fact makes it necessary to employ compound engines that are about twice the capacity, referred to the L.P. cylinder, of simple engines that will take charge of the same maximum load-curve peak and will not be so enormously too large—and therefore wasteful—on mean load. With a battery, the steam engine can be of such reasonable size as will carry the mean load economically, and it may be of an economical type, compound or even triple expansion.

The load curve of a traction plant is so quickly variable from minimum to maximum that, so far as the steadying effect on steam consumption of an accumulator is considered, this may be neglected. Any ordinary boiler will serve. But a very serious economy in boiler cost may be secured by the use of batteries, exactly to the extent, in fact, of the economy of the engines on a steady load.

English tramways show results agreeing with the approximations I have put forward sufficiently closely for the figures to serve as a basis in estimating requirements.

Mr. REGINALD WOOD (*communicated*): I regret my inability to be present at the reading of Mr. Highfield's paper. This beginning of the attempt to use accumulators in a scientific manner is very welcome. Mr. Wood.

It will probably be undisputed that in many large undertakings the rate of generation should be constant over long periods, say days, weeks, or months, and the excess of supply over demand should charge the accumulators in outlying districts, whilst the accumulators should discharge the excess of demand over supply. There will be transitionary states in most undertakings when this ideal is not the most

Mr. Wood. suitable method of working, but the ideal should be kept steadily in view.

In large towns the greatest enemy of the accumulator is the foggy day, which would necessitate a high rate of discharge over eight or ten hours.

The author is to be congratulated on his courage in providing the exciter. A source of constant pressure is often useful. Unfortunately in this case the object is not obtained, since the pressure of the exciter will be subject to slight variations. The automatic arrangement is, as the author admits, susceptible of improvement.

The lamination of the booster is a step in the right direction. Perhaps a condenser to shunt it might be made.

Since the booster is to run continuously, it would appear that the number of cells should be line pressure divided by mean cell pressure, which latter is given as $\frac{1{\cdot}9 + 2{\cdot}4}{2} = 2{\cdot}15$. This would decrease the size of the booster and its companion machine.

It would be interesting if the author would explain why he is not troubled with sparking with a large armature current and a weak or no field. It has often been urged to the writer that the contrary would be the case in the absence of special preventive measures.

Mr. Hewlett. Mr. E. HOLCOMBE HEWLETT (*communicated*): In reference to the keeping of the load on the generators in a traction station constant, an arrangement which I had made for the power-station of the Mount Morgan Gold Mining Company, and which was worked out for me by Messrs. Crompton and Co., appears somewhat less complicated than that described by Mr. Highfield. In this instance only one machine is used. The poles are laminated; one magnet-limb is wound with a shunt energised directly from the bus bars of the switchboard, and the other with a series winding through which the whole, or a definite portion of the total output of the station passes. The two windings are connected so as to oppose each other. The armature is in series with the battery. The action is as follows: When the output exceeds the normal load of the generators at work the series winding preponderates, and helps the battery to discharge; when the output is under the normal load of the generator at work, the shunt-winding preponderates and the battery takes a charge. The action is perfectly automatic, and the pressure with rapidly varying loads is practically constant. By adjusting the resistance in the shunt-field of the booster, the point at which it reverses, can be altered within rather wide limits to suit the requirements of the battery. The generators are compound wound for constant potential. Where lighting has to be done from the same plant the use of shunt-wound machines with a small battery, such as is considered here and in the paper, is not desirable, as in case of a mishap to the booster, or a necessary battery cleaning, the lighting would be unsatisfactory. The machine mentioned is, I believe, the first of its type, but I understand several others are now in use.

Mr. Highfield. Mr. J. S. HIGHFIELD, in reply, said: Mr. President and gentlemen, I am exceedingly gratified that so large a number of gentlemen interested in this matter have given us so many practical details on the

Mr. Highfield.

subject, and I am glad to say that I have gained what I hoped from the discussion—a very greatly extended knowledge of battery working. I gather that Mr. Shoolbred considers that as the station grows larger, the use for the accumulators rapidly decreases. It is to that statement I object: it is against the principle that batteries are useful in small stations and not at all useful in large stations that I wished to direct the paper. I quite admit that with a large station one would always run three shifts under all conditions, but that batteries are of no use in large stations I cannot admit at all; because although in a large station, through having a large number of units, or what I may call graded units, it is perfectly simple to keep the load on the running generators constant, at the same time there is the difficulty that the load cannot be kept constant on the boilers and steam-pipes. I am now speaking of lighting stations only, and it seems to me that it is equally important to keep the load on the boilers and steam-pipes constant as to keep the load on the generators constant, and it is for that reason that accumulators are required. One objection to accumulators has not been raised, but I think you will forgive me for mentioning it, namely, that generally raised as to certain towns—like Glasgow, for instance—which suffer or are benefited by heavy fogs in the winter; it is objected that accumulators would be quite useless to tackle the all-day load that exists in such cases, because any reasonable size of battery could not give the output all day. As a matter of fact you do not want it to do anything of the sort. In the text I gave a case of a station with four units and a battery equal to one of these units. If a fog comes on, although the load in the day is very much heavier than it would be without a fog, it does not come up to the top peak; and as long as the accumulator is big enough to take that peak—that is to say, $\frac{1}{4}$ to $\frac{1}{5}$th of the top load, then the spare plant can be run at the top of the peak and the accumulator treated as spare plant, and if a breakdown occurs the accumulator is available. Of course nobody would try and discharge this accumulator on a load beginning at six o'clock in the morning and try to keep it on the whole day. Mr. Shoolbred also complained a little of my figures, and I believe Mr. Esson did the same thing. I am willing to admit that the arrangement of the figures has no law whatever, and I am much obliged to Mr. Esson for pointing out the relation there is between those figures; but it seems to me it only proves what I say in the first part of the paper, that the practice has been in relation to accumulators to start up with a very good and useful little battery, and to use it in a perfectly proper way for perhaps twelve months. Perhaps it is used to work the night shift; then it becomes a little too small for the night shift, but the men are not going to say so, till the battery is ruined by over-work; then they say the accumulators are no use, and extensions to the plant simply consist in putting down more generators, and the accumulators are left alone. I was very interested to hear that Mr. Patchell has found the same benefit from the use of boosters that I have found in connection with a lighting-load, and it is very satisfactory to hear that the efficiency is also at least as high as I have given it, and that in some cases he can get it even higher than that. A series-wound booster was proposed, I think, by Mr. Sayers, for the purpose of an

Mr. Highfield. automatic reversible booster. A series-wound booster will only partially do the work, because these reversible boosters must take account of the variation in the battery pressure. Unless they do that in an absolutely perfect way they are not perfect boosters. No series-wound booster can take any account whatever of the variations in the battery pressure, which depend simply on inherent qualities of the battery, and do not depend on the current that comes out of it or goes into it; they depend simply on its state of charge. It is also satisfactory to hear from Mr. Sayers that he has found great benefit from charging the lighting battery from the traction plant. That is one of the chief points I mentioned in the paper in using batteries with combined stations, that if regulating cells are not used, and a 460, 480, or 500 volt three-wire system and a tramway system exist, two indentical batteries can be used for either lighting or traction, or in any way that is found useful, and thus a certain amount of energy can be transferred from the traction units to the lighting load. The high efficiency of the battery as used on the traction load of course does not depend on the use of the reversible booster. The reversible booster simply enables the battery to be worked at the one-hour rate of discharge, or even at a greater rate, and to be charged automatically during ordinary running hours, but it does not have any effect at all on the efficiency. The higher efficiency obtained is certainly due to the fact that the charge takes place and the discharge immediately follows it, and then that discharge is followed by another charge. The efficiency has nothing to do with the booster. The efficiency I give of 81 per cent. does not include any loss in the booster; it is simply the battery efficiency, the watt-hours taken out of the battery and put into the battery. The whole efficiency of working, I think, is quite fully given in the appendix. Professor Wilson has very kindly criticised this paper, and I am very much gratified that he has spoken on it, because I owe to him my early training in experimental work. He has described a booster built by Siemens and Halske. I am afraid my paper gives the impression that there is but one automatic reversible booster, and that the one I have described. Naturally I think it is the best reversible booster, but that it is the only one I do not for a moment think, and Professor Wilson has explained to you this very interesting machine due to Siemens and Halske. That machine depends on the action of two windings, one against the other, and the magnetising force in the booster fields simply depends on the difference between the ampere-turns of the two coils. It is therefore necessary to have a very much greater weight of copper on such a machine than is required on a machine that does not depend on the differential principle, and probably the reason why the exciter was added to that machine was because with the two coils on the booster fields the machine was very difficult and costly to build, owing to the great weight of copper required.

As a matter of fact there are boosters known and made where the coils are placed, instead of on a separate exciter, on the booster fields themselves. The reason, probably, that Siemens and Halske did not put those coils on the booster fields was, that it would have made the machine exceedingly cumbersome and that it was much better to put,

Mr. Highfield

perhaps, eight times the amount of winding usually necessary on a little machine than on a big one. That probably explains the use of the exciter in that particular machine. There is one very serious objection to the design of this machine, namely, that one of the coils, the fine-wire coil, is excited from the battery pressure, and when the battery pressure is high that coil will have a greater power than when the battery pressure is low. To some extent it takes account of the variation of the battery pressure which, as I think I said, these boosters must do, but it does not take account of the full variation. The differential action depends on the coil connected with the battery, and also on the second coil through which the whole or a part of the line current flows. In a small station it is a very frequent occurrence for the whole current on the line to go off, for the load to fall to zero, and it is very common indeed, even in stations of moderate size, for the current to vary between very large limits. When the current goes right off, the boost immediately rises to the maximum, because the differential action is done away with and then the boost depends on the action of the one coil only; the result is to force a tremendously heavy current into the cells, which usually will cause damage. If it is only required to work between small limits, say with a load that varies from 500 to 700 amperes, such a booster would be fairly satisfactory; but if it is required to work from zero up to any maximum, then such a booster would want watching at least at all times when the cells were nearly charged, or the rate of charge would be too high. Colonel Crompton has suggested that this booster is not novel, and that a booster of similar pattern was patented in America some years ago. I can only say, if that is so, that this is another case of injustice from the United States, because I have also been granted a patent in that country for the machine described. It is satisfactory to me that Colonel Crompton corroborates my figures from his very extensive experience of accumulators. I referred in the paper, and I made rather a point of it, to curve 18, connecting cost of working with load factor. I looked up a good many papers on the question and, as I explained, I came across the first figures on the subject yesterday that in any way corroborated this curve. I am very pleased, therefore, to have the further information on the subject from Mr. Esson, which I shall embody in the form of a curve to compare with that shown in Fig. 18. I do not know whether it interests anybody here, but that curve is very nearly a hyperbolic curve.

(*Added July* 8, 1901.)

In the brief remarks made above, I have not done justice to Mr. Shoolbred's interesting contribution to the discussion. It would appear that Mr. Shoolbred considers that a battery is a necessity in any direct-current station, however large, to serve chiefly as a means of regulating the station pressure; although as a store of energy, it is not by any means so necessary or useful as in a small station. I think, however, that even with existing storage batteries, which are not nearly so satisfactory as they might be, that their use as a store of energy is of immense convenience and economical utility in connection with any station, however large.

Mr. Highfield.

There appears to be some fear in the minds of several speakers that the reversible booster is an additionable complication in the station; this is by no means the case. It is only necessary to see a battery arranged for control by a reversible booster, to be convinced of its great superiority over any other system of regulating; further than that, on a battery of any size the cost of the reversible booster with its switchgear is very much less than the cost of the regulating cells and their leads and switches. As a matter of fact, even with regulating cells, it is necessary to use a booster of some sort, or else to use a special dynamo for charging, and if the cost of the special dynamo or booster is taken into account, the whole arrangement with regulating cells will be found to be two or three times more costly than the arrangement with the reversible booster, besides being very much more complicated. These remarks apply only to batteries used for lighting work.

With a battery used for tramway work, regulating cells are an impossibility, and then it becomes a question of connecting the battery in simple parallel on the line, or using a reversible booster. In the first case a battery cannot be worked except at low rates of discharge, owing to the variation in pressure, and it cannot be worked with compounded generators, and further than that, it cannot be charged in the ordinary working hours; a booster of sorts will also be required to charge it up at some time. With the reversible booster, the battery will charge itself automatically at any time during working hours. The battery will work at any discharge up to its one-hour rate, and the difference in cost of the special reversible booster and an ordinary booster is very much less than the difference between two batteries, one working at the one-hour rate, and the other working at the three-hour or four-hour rate. The booster, once it is started, requires absolutely no attention, and involves no complication; the switchgear in connection with the booster and battery is quite as simple to operate as the switchgear required for paralleling compound generators. In fact, as Mr. Trotter neatly puts it, the booster does all the thinking.

Mr. Trotter pointed out that the amperes per car shown in Figs. 11 and 12 are only about 12. The cars used in St. Helens are chiefly large double-decked, double-bogie cars, seated for 79 passengers. The mean number of units used per car-mile, taken over a period of seven months, is 0·96, which gives 19 amperes per car. In Fig. 11 the generator was running at top load, and the mean current on the generator was not quite sufficient to keep the battery up to the mark—in fact, the battery was discharging. The same thing occurs in Fig. 12, where the battery is again discharging more than it charges.

The working of the station is always arranged so that the load on the boilers is kept as nearly constant as possible, so that when the heavy lighting peak is on, the traction battery is allowed to discharge considerably; therefore at such times the load on the engine is not really the mean load required to keep the line running. At other times, the load on the engine is considerably greater than that required to keep the line running, so that the batteries at the end of the day are fully charged.

Mr. Highfield.

With regard to Mr. Esson's interesting remarks as to the connection between load factor and cost per unit, the accompanying curve *A* is plotted from the figures he gives; *B* is the curve shown in my figure 18, which I have put alongside Mr. Esson's curve for comparison. It appears to me that the curve will differ for different plants; that is to say, the greater the number of units into which the whole plant is divided, the greater will be the length of steam-pipes, and, generally speaking, the greater will be the stand-by losses, and therefore the greater will be the value of *a* in Mr. Esson's formula. It is not sufficient to consider only the load on the engine, as although the engine itself may be making excellent use of the steam supplied to it, the steam-pipes may be wasting an enormous amount of steam supplied to

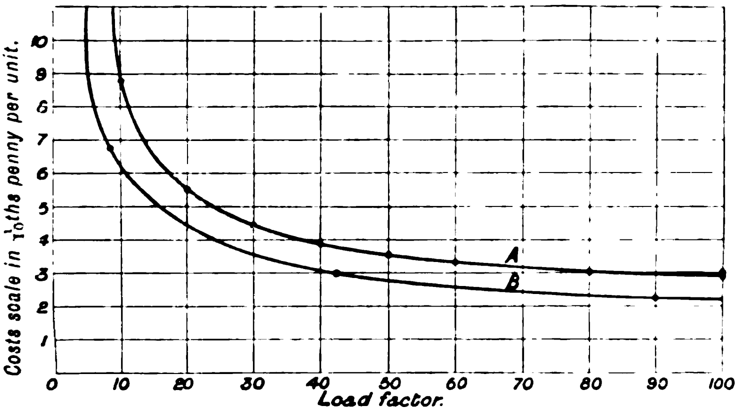

FIG. E.

them from the boiler, and the boiler also might be working inefficiently, and it is the relation between the whole cost of operating and the load factor that I wish to get at. It would appear, however, that with a very small load factor it is much more important to cut down the number of units into which the plant is divided, and hence the length of steam-pipes, than when the load factor is a better one.

Mr. Booth, in his communication, suggests that the fuel consumption varies inversely as the load factor. Since the fuel is really the largest item affecting the cost per unit, Mr. Booth's curve connecting load factor and cost would be a straight line. From the result of experiments, I am inclined to think that this is not correct, and that whatever the result be, the decrease in cost is most rapid as the load factor improves from a very small value to a higher one, but that after the load factor reaches 60 per cent., the reduction in cost per unit as it is further increased is but small. It is pleasing to find Mr. Booth entirely at one with those who consider a battery to be almost a necessity in small power-stations.

Mr. Wood suggests a formula for determining the number of cells for traction purposes. It is not very material whether 240 or 250 cells

Mr. Highfield.

be used. There is an advantage in using the smaller number, because if the booster should break down, the battery will always be sufficiently charged; whereas with the greater number it would probably be never charged properly till the booster is repaired. It is this sort of treatment that so quickly spoils a battery.

In designing a battery for lighting work, it is generally most convenient to take the number of cells which will supply the all-night load at the required pressure without any regulating. Generally speaking, if the battery is figured on the basis of two volts per cell, with a small margin allowed, it will be exactly suited for its work. When batteries are to be designed for a combined station, it is best to decide on the number required for a lighting battery for any pressure between 460 (or even 440 volts) and 500 volts, and to work out the battery for the traction load of exactly the same size and with the same number of cells.

Mr. Wood seems to doubt that the automatic control of the booster by the exciter is sufficiently accurate. By the use of compound windings I have found no difficulty in controlling the pressure within two or three per cent. limits, which is close enough for all practical work. I think the recorder curves, Figs. 15, 16, and 17, show that even with an uncorrected booster very good results can be obtained.

Mr. Hewlett's description of battery plant is most interesting. Batteries usually have such very rough handling in works that I have always rather hesitated about using them, although an immense saving in the cost of power can be made in most instances. The booster described by Mr. Hewlett appears to be somewhat similar to that described by Professor Wilson, the only difference being, apparently, that the shunt-winding is connected to the bus-bars, whereas in the other case it is connected to the battery terminals.

I have now completed the accounts for the past year's working at my station, and I have been interested to find that the cost per unit sold for coal is 0·35d. with Lancashire thro' and thro' at 12s. 6d. per ton. The previous year the cost per unit was 0·39d. with fuel at an average price of 8s. 6d. per ton; slack at 7s. was used for five months, for the remainder of the year slack at 7s. and thro' and thro' at 10s. were used. The battery plant having only been in operation eight months out of the year, I hope for still better results this year.

In conclusion, I should express a hope that from so many engineers speaking as to the advantages of batteries, that the battery makers will set to with even greater energy than they have hitherto used to turn out a still more reliable battery than they make at present, and one which shall be less expensive and have a longer life.

The President.

The PRESIDENT: I will ask you to give a vote of thanks to Mr. Highfield for his excellent paper.

The vote was carried by acclamation.

The PRESIDENT announced that the scrutineers reported the following candidates to have been duly elected:—

Members.

Arnold Lupton.	Gustavus J. Melms.

Associate Members.

Llewellyn Burbank Codd.
William Cotsworth.
Michael Culligan.
Ernest Slater.

Associates.

John Anderson.
Ralph Melville Archer.
William Moore Bell.
Henry Edmund Brain.
P. R. Friedlaender.
Ernest Wilfrid Lawson Harrison
Charles Isaac.
Frederick Wilberforce Thompson.
Gavin Knox Walker.

Students.

Harold C. Gunson.
George Frederic Hoyland.
Robert Livingstone.
Thomas Benjamin Lowman Newstead.
Alexander Richard Newman.
Edward John Otley.
Alfred Raworth.
Walter Clitheron Smith.
Albert Williams.

MANCHESTER LOCAL SECTION.

Paper read at Meeting of Section, Feb. 26th, 1901.

ON THE USE OF STORAGE BATTERIES IN CONNECTION WITH ELECTRIC TRAMWAYS.

By G. A. GRINDLE, M.I.E.E.

The excitement that attended the introduction of the storage battery to the public in a practical form, some twenty years ago, is doubtless well within the memory of many of those present this evening. To those to whom it is not, it would be a lengthy and almost impossible task to even attempt to describe the enthusiasm with which it was hailed, or to recount the marvellous predictions of the wonders it was destined to effect.

The oft-repeated story of the wonderful box with the millions of foot-pounds of energy in it, and its celebrated journey from London to Glasgow, first heralded forth to the world through the columns of *The Times*, is now ancient history; but at the time when everything was electrical mad, it was just the incentive wanted to cause imagination to run riot.

A glance at the Patent records of those days, when provisional patents were published, is a most amusing means of verifying the fantastic ideas that prevailed as to what or for what a storage battery was or ought to be. As can very naturally be supposed, it was eagerly seized upon as the great solution of all the difficulties which beset electric traction, in which practically nothing so far had then been done, mainly owing to the difficulty of getting the power to the car, in those days the trolley system being undreamt of.

With the perfected accumulator, as it then posed to be, all these difficulties vanished in the eyes of the enthusiasts, and the hopeless attempts to solve the difficulty by means of Bunsen and other types of primary cells were forgotten.

All these hopes, however, were doomed to disappointment, and for upwards of ten years no practical result of the storage battery marks the pages of the early history of electric traction.

During that period, from time to time spasmodic efforts were made to introduce storage battery traction on different lines, but with very indifferent success. Every new accumulator that came to light—and their name in those days, as now, was legion—was duly announced as being the cell that was to solve the electric traction question ; but nevertheless the problem remained unsolved, and up to the present time (in Great Britain at any rate) no practical demonstration has taken place that can be deemed an unqualified success.

It is not my intention in the present paper to discuss this particular problem of the application of storage batteries to electric traction, and I purpose only making a passing reference to it.

The problem is an extremely intricate one, and one which I regret to say I feel absolutely convinced has never had the attention paid to it that its importance merits. The cocksureness with which it was first looked upon as a certainty undoubtedly seriously militated against its success, or, more properly speaking, perfect development. If a line was a failure by any other system—by reason of its nature, the amount of its traffic, or by any other cause whatever—it was promptly offered to the first storage battery advocate that came along, who promptly started in with the idea that it was simply the storage battery that was required to be the salvation of the line, no attention whatever being paid as to whether there was the capability in the line itself being a paying concern, or as to the mechanical equipment involved.

The most serious attempt made in Great Britain so far has been that made at Birmingham commencing in the year 1890, but here the result has been, owing entirely to the nature of the equipment and the capacity of the line, anything but a success. Up to 1894 the losses on the line were attributed to the cost of up-keep of the batteries. At that date, however, with the view of ascertaining the true facts of the case the supply of batteries was undertaken on a definite figure per mile. Since that date unfortunately and significantly no data of running costs has been forthcoming, but batteries have been supplied and car miles run to the extent of over 1,100,000 miles, and from the accumulator view of cost, with highly satisfactory results. With

accurately kept figures on an aggregate mileage of this amount something more than theoretical calculations can be obtained, and the result is such as to firmly convince me that in spite of its failures hitherto there is a very great future before this method of traction. Its adoption at the present moment in New York on Thirty-fourth Street is attracting considerable attention. The closest attention is there being paid to details, and in view of the extended experience available as to mechanical equipment and its problems, the system will most probably at last have an effective opportunity of demonstrating its capabilities. As with the trolley system, America promises to demonstrate to this country the value of the storage system, and how to operate it.

To revert, however, to the early eighties and the progress of other systems of traction, in Great Britain the usual result which seems by fate to attach itself to all new ideas ran its course, namely, a laudable effort, and then a long tedious period of inactivity.

The first serious attempt at electric traction was made at Portrush in Ireland, when in 1882 a line was equipped on the third-rail system some six miles in length, running from Portrush to Bushmills, and some years later this was followed by a second line in Ireland, on somewhat similar lines, running between Bessbrook and Newry, with both of which your chairman for the present year was closely identified, and in the case of the second one, was actually responsible for. In the meantime abroad, far more particularly in America, matters had been marching steadily onwards. The third-rail system, as adopted on the two lines just mentioned, was experimented with on several lines, but after having been given a careful trial, was found to be wanting, at any rate in its capacity to meet the demands of American practice; and somewhere about the year 1884 the idea was conceived—by whom actually I believe some doubt exists, the idea having been claimed and attributed to several—of stringing the conductor overhead from pole to pole, and obtaining the power from it by means of a collector. It is an interesting fact that a similar method of collecting power was adopted in the same year on the Bessbrook and Newry Tramway, where at wide road crossings the third rail was interrupted, and the current

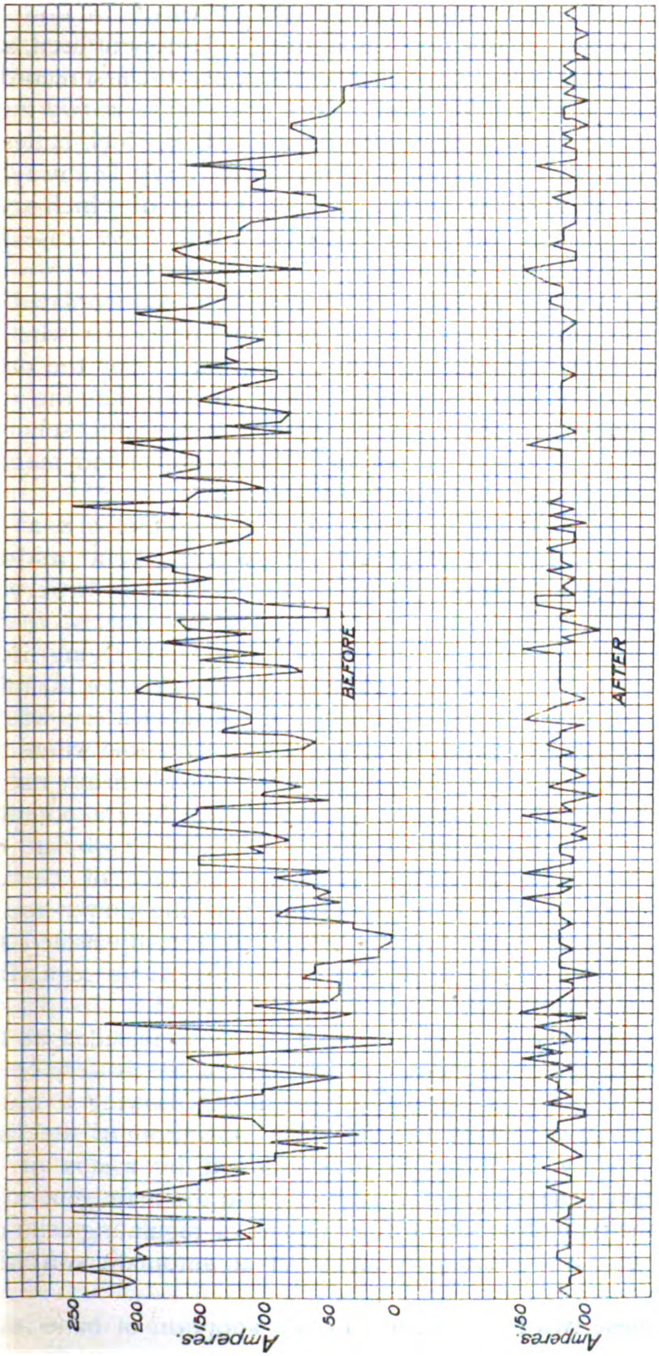

DIAGRAM I. | Load Variations before and after Storage Battery Use.

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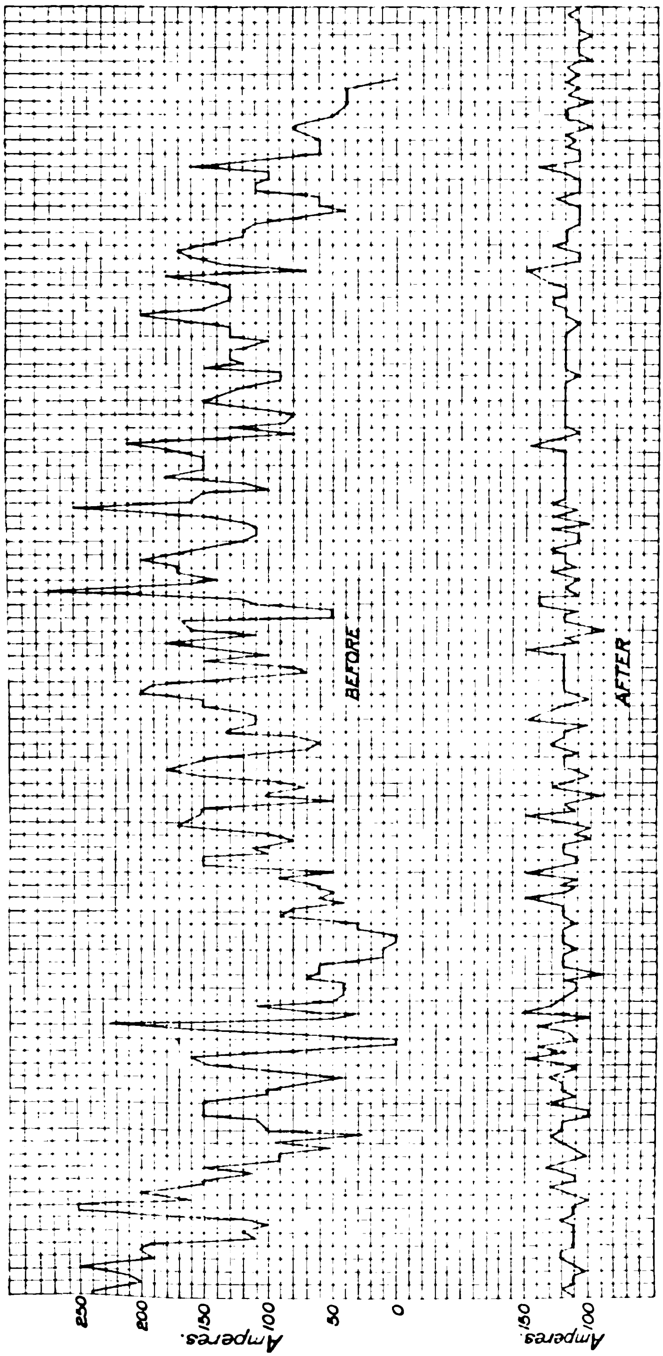

DIAGRAM 1. | Load Variations before and after Storage Battery Use.

collected from a suspended overhead wire. In none of these schemes, however, was a storage battery utilised, and it was not until ten years later, or 1894, that the first recorded instance of its employment occurs. In that year, two tramway systems came into operation on both of which batteries were adopted, one being the Douglas & Laxey Tramway, in the Isle of Man, the design and equipment of which again your chairman was responsible for ; the other case the Zurich Electric Tramways.

As to on which system it was first contemplated to employ accumulators it is impossible to say, or whether the designer of either scheme was aware what the other was doing or contemplating. It is possible that the idea of employing batteries was arrived at in both schemes entirely independently. At any rate the object and method of employing them was entirely different.

In the first instance the battery was employed at an outlying substation situated somewhere about midway between the terminal points of the line. The battery in this instance was operated by means of a special feeder from the generating station at Douglas, the charging being effected by means of an ordinary motor generator installed in the battery-house. The function of the battery was to assist the line load, which at the point of the line where the battery was installed was of an exceptionally heavy nature at times, generally to assist in maintaining the line potential at or about the centre of the system, and to obviate the necessity of sending the maximum amount of current demanded over the long feeders from the power-house. Variations of the battery potential were compensated for by a portion of the battery being employed as regulating cells, the regulation being effected by hand.

In the second instance the battery was installed at the power-station, the principal functions of the battery being to equalise the load on the generators, allowing a much smaller power plant to effect the operation of the line. The battery in this case was charged by means of an auxiliary generator in conjunction with the main generator, and the regulation effected by means of regulating cells cut in or out as necessary by means of an automatic switching arrangement.

These two first instances of the adoption of batteries to

traction working, though neither of them can, when compared with recent practice, be considered as ideal methods of employment, nevertheless are distinctly interesting in view of subsequent development, and have gone far to demonstrate the

NECESSITY FOR A STORAGE BATTERY.

One has only to take a glance at the load curve of any traction system to see the necessity and call for the employment of a storage battery. The usual load curve reminds one of nothing so much as an attenuated mountain range, with one moment lofty peaks ranging skywards, and the next moment low-lying passes down at times to "sea-level."

The load curves that you have in your hands will very clearly show this, and though the wide ranges may tend to decrease in number on large systems, the liability to their occurrence still exists and has to be provided for.

Nothing more detrimental to a generating plant can well be imagined, the violent stresses between full and no load occurring so suddenly, and often consecutively following on each other. The necessity also arises when it is desirable to maintain the voltage as nearly as possible constant. No matter to how fine a point the governing of the engine is carried, it is impossible for it to respond with anything like the rapidity with which the variations in the load take place. The most perfect mechanical governor has a distinct time-factor as compared with that of switching on a motor, nor can even a generator itself respond so quickly, with the result that the voltage of the line rises and falls.

Diagram No. 1 shows an interesting example of the difference of the load on the generator obtained on the same line before and after the installation of a battery under precisely similar conditions. Diagram No. 2 shows the results obtained in the variation of the voltage. The upper curve in each diagram giving the result before, the lower after the employment of the battery; the upper curve and lower curves in No. 2 show the results upon the voltage before and after respectively.

The variation in the load you will note on Diagram No. 1 before the introduction of the battery was as high as

720 amperes, while subsequent to the employment of the battery it amounts to 50 amperes only.

These curves, however, must not be taken as in any way approaching what can be effected with a battery. In this instance the battery was installed without any boosting or special compensating arrangements. In conjunction with a suitable booster there would be at the least as much improvement again. The results to be obtained by employing a suitably designed booster will show as great an improvement over the results obtained by the employment of a battery, as the employment of a battery shows over working without.

A battery is further a distinct necessity where it is desirable to centralise as much as possible the operating plant, as is nearly always the case, and often save an additional station with its attendant staff.

A battery is an absolute necessity where the available power is limited to little more than the mean day load, as is often the case where water power is employed—and in many instances small falls of water which by themselves would be quite inadequate to successfully operate a small line, with the assistance of a battery can do so easily.

Admitting, therefore, the necessity for a battery, we will next consider

The Advantages to be Obtained

by the inclusion of a battery on the power system.

The first and undoubtedly foremost advantage to be gained by a reliable battery, properly installed and duly proportioned for the work it has to effect, is the simplification of the question of generation of energy, resolving this from being one of a constantly varying nature, varying from nothing to several times its mean, to the one simple question of generating an even, steady, and predetermined load. By enabling the prime motor to be run constantly at an even load, it naturally follows that this load can be arranged to be the most economical one for the motor employed, which will result in an enormous economy over what could be obtained by employing a prime motor, which would of necessity have to be at least three times its size, in order to enable it to cope with the maximum demand, which may

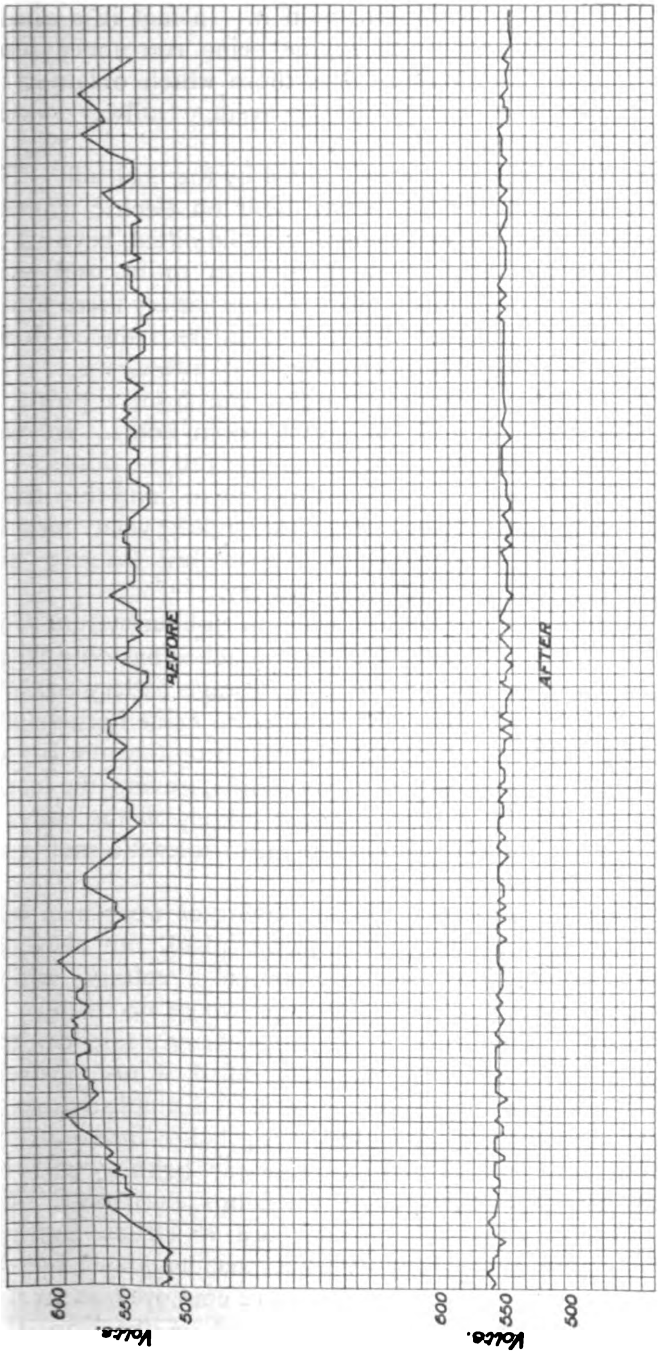

DIAGRAM 2.—The Voltage Curves in a Station before and after installing Storage Batteries.

from *time* to *time* be thrown upon it. In fact it is almost impossible to conceive an engine being run under more disadvantageous conditions than those which obtained in the production of energy for an average railway system where no battery is employed.

This advantage is best evidenced by the coal bill. The pounds of coal per horse-power hour on electric traction systems is, I think it will generally be admitted, beyond all reason, in many instances ranging up to 10 lbs. and even more—by the employment of a storage battery there is not the slightest reason why this should not be reduced down to the best engine practice, namely, from 2 to 2½ lbs.

An advantage, and an important one from a point of cost, is the reduction of the engine-room hours. In this country few, if any, tramways run the full 24 hours, but where they do (and it is as well to bear in mind that there is a growing tendency towards its adoption) what may be termed the "night-load" is of the smallest nature; this load can be taken entirely by the battery.

Apart from the question of where a 24-hour system is in force and where the current English practice has only to be provided for, the employment of a storage battery enables a considerable reduction of hours to be made in the daily work, and will in most instances easily bring the running of the station within the limits of two shifts, leaving the early and the late cars to be both operated entirely off the battery. In an average station this should mean at least a saving of rom £150 to £200 per annum.

It is a distinct advantage in the saving of wear and tear of machinery, not only in the power plant, but also the cars; the sudden and violent variations of voltage, which must of necessity continuously occur where no battery is used, throw a large amount of unnecessary strain on the running motors, which is much modified, if not entirely eliminated, when a battery is employed. A distinct advantage is shown in the running of the cars; better time can be kept and more even running. The car lighting will be steadier, and the destruction of lamps decreased. An important advantage is the safeguard it effects against accidents, more particularly fly-wheel accidents and breaking of belts in cases where the latter are employed, as in the event of a "short" or sudden overload on the line, the

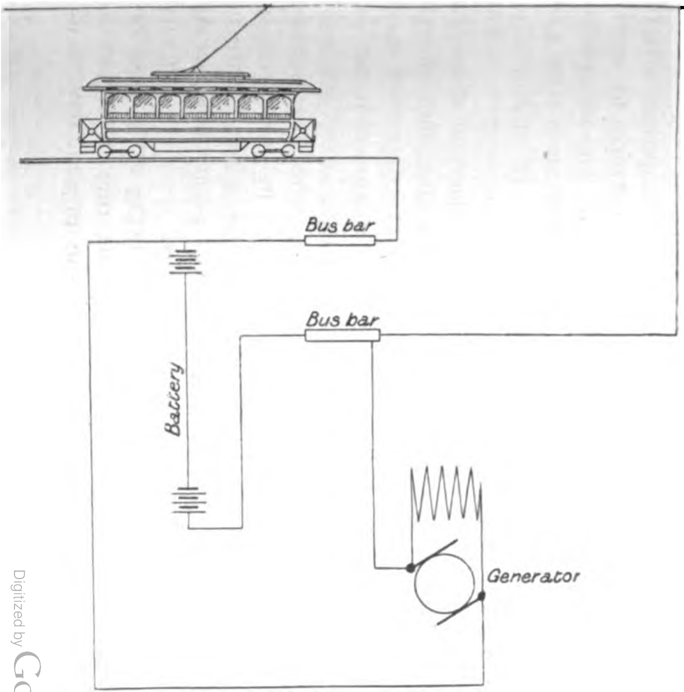

DIAGRAM 3.—Showing Arrangement of Generator and Battery (at Power-House), no Booster employed.

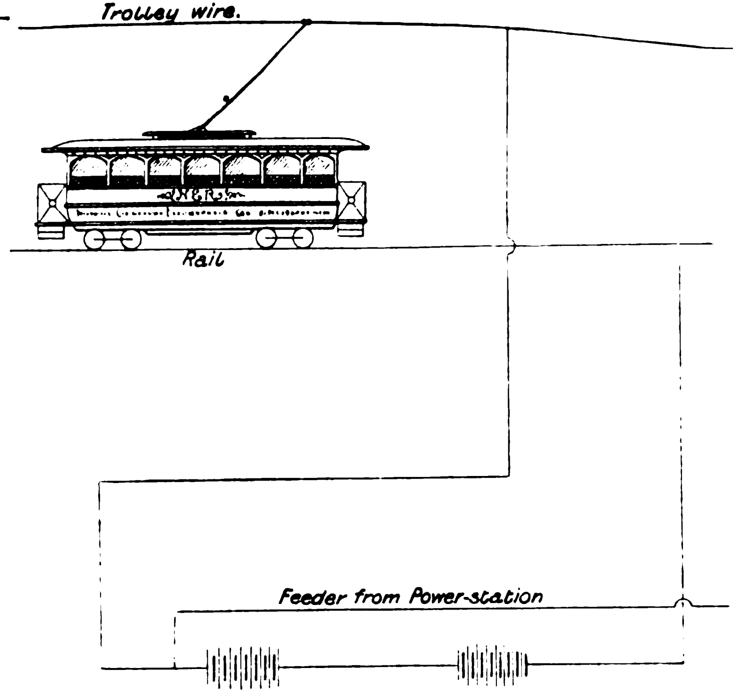

DIAGRAM 5.—Battery across Main at Sub-station. Battery in Outlying Sub-station.

(*For Diagram 4*, *see p.* 1109.)

extra demand of current will be immediately taken by the battery and not by the generator. Should the "short" be sufficiently great to throw out the circuit-breaker, there will still be no variation on the generator load, the battery absorbing it all; while when the circuit-breaker is closed again, even though the cause of throwing it out may have been removed, there is almost certain to be an abnormal demand on the line for current, due to the almost simultaneous re-starting of the cars. All this will be immediately taken by the battery, without any abnormal load whatever being thrown upon the engine. In fact the investment in a battery may be looked upon as a very excellent form of machinery insurance.

In cases were belts are used for driving, experience has shown that where a battery is not employed, a severe shock will almost invariably break the belt before releasing the cut-out. While, where a battery is in operation, the circuit-breaker will invariably operate first, saving the belt.

Another advantage, and one of considerable importance, is that the battery will often carry through where, without one, a stoppage would be absolutely inevitable. I do not say that every accident which has caused the stoppage of an electric line might have been prevented by the employment of a battery: but a vast number of stoppages which have occurred have been due in many instances to mere trifles, and would never have taken place. The advantage of being able at any time to shut down an engine for a few minutes, I venture to think, will be universally acknowledged.

A very strong factor amongst the advantages of employing batteries on traction systems is the facilities they afford when, as is often the case, extensions or increased car service become imperative. By the installation of batteries at the extremities of existing lines extensions become feasible without any interference whatever with the existing arrangements and consequent expense—in many cases saving the necessity for additional power-substations, which, unless the extensions are very great, must work under most disadvantageous conditions.

Having admitted the necessity and the advantage of employing a battery, there yet remains one great factor to be consulted, and one which in the present day there

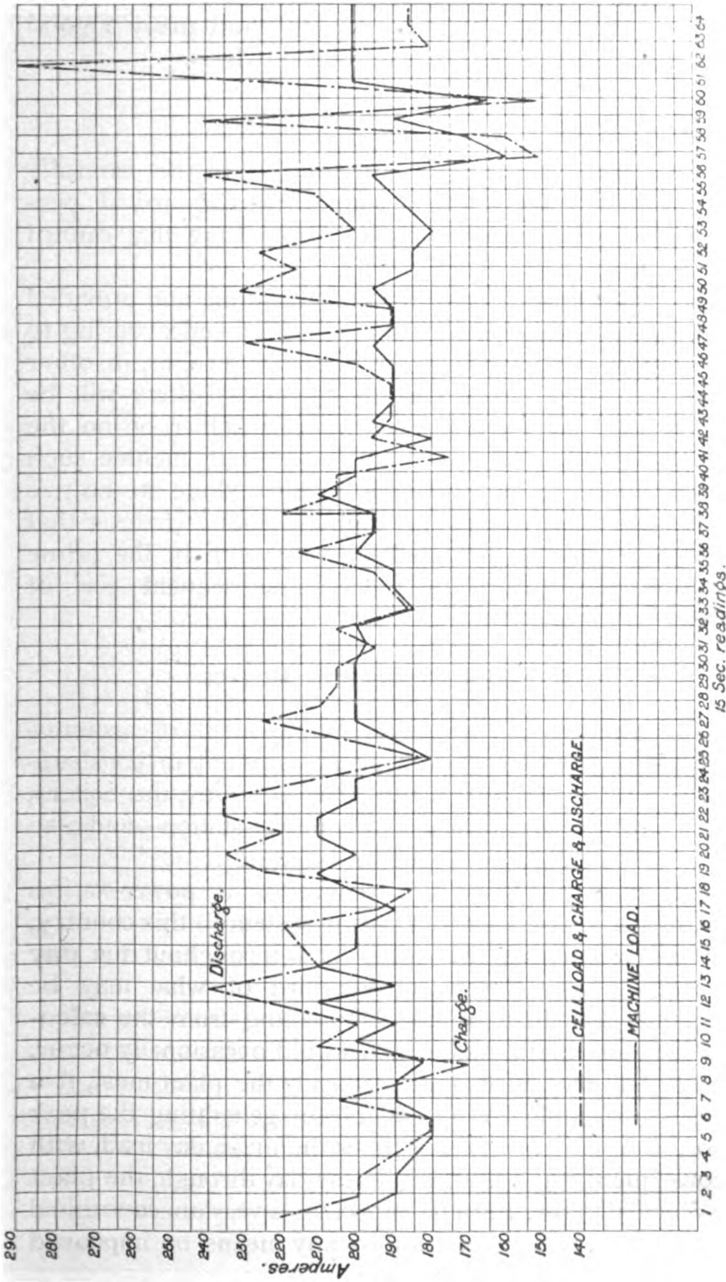

DIAGRAM 4.—Curves from Generator and Battery without Booster on Tramway Load. Hour-Discharge-rate of Battery, 190 Amperes, Battery at Power-House.

is a very lamentable tendency to unduly exalt, and at the shrine of which many a good scheme and many a good job have been unfortunately sacrificed. It is

The Question of Cost.

There are two things that require to be carefully avoided—first, schemes that cannot possibly pay if properly carried out; second, lavish expenditure that cannot be recouped.

Eliminating these from our consideration, and provided that no cheeseparing policy is adopted of endeavouring to make one pound's worth do the work of two, or, in other words, it being ensured that an adequate battery will be properly installed and equipped, as to whether or no the necessary outlay which must be incurred to include such a battery on a traction system is justified there are no two questions, as there is not the slightest doubt whatever that it is the means of a material saving both in the prime outlay on operating plant and the subsequent cost of operation of same.

Saving in Operating Plant.

The judicious and adequate employment of accumulators will very materially reduce the amount in construction cost of a generating plant—that is to say, the boilers, engines, and the generators at the power-station—and also in consequence the cost of station buildings.

If we take a typical load curve of a power-station operating an average-sized tramway system in this country, it will be found that the mean load throughout the day approximates very closely to one-third of what may be termed the peak load or line, eliminating from the calculation the abnormal peaks, which would occasionally occur. To meet this load fairly and effectively the plant must, if a battery is not employed, be capable of generating the peak line, or, in other words, three times the mean day load, with the consequent result that, taking the day through, the plant is only loaded to one-third its capacity—a very uneconomical state of affairs, which will not by any means be improved by the varying nature of the load.

Diagram No. 10 is an interesting example of this,

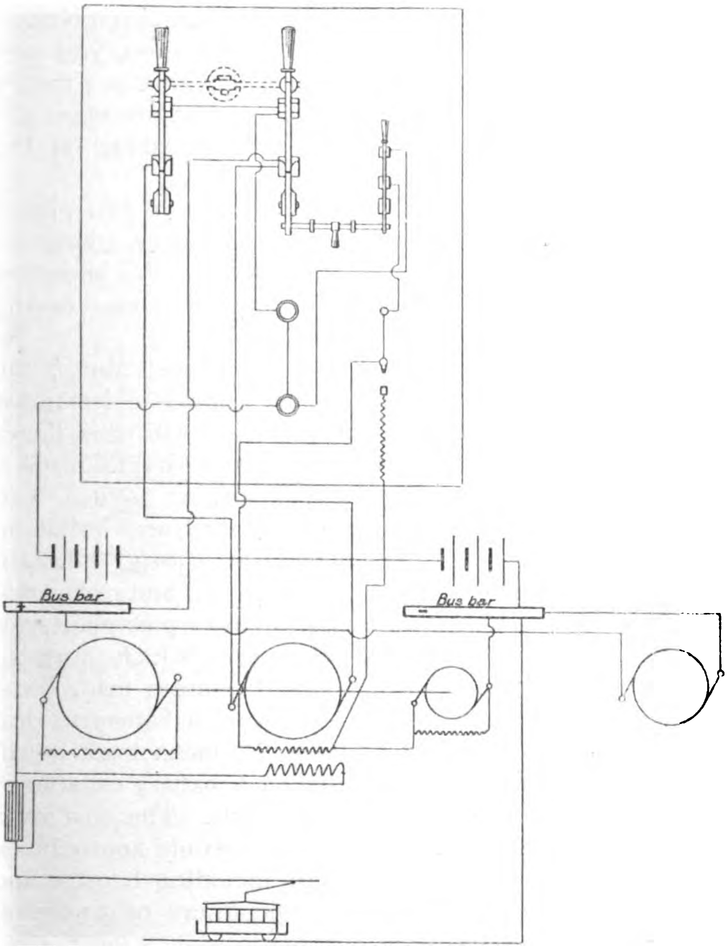

DIAGRAM 6.—Showing General Arrangement of Reversible or Differential Booster.

showing, so far as the upper or "load on line" curve is concerned, even a more aggravated state of conditions. The generator in this case is steadily doing the mean day load, and the battery is dealing with everything above. These readings were taken every five seconds for a period of five minutes at the time of heavy load at seven o'clock on a September evening. The load variation, you will notice, ranges from 15 to 250 amperes, and that as a matter of fact no part of this extreme variation came upon the generator, the generator output actually falling at the moments of heavy load.

Let us for a moment compare the cost of two plants, one operating without and one with a battery, taking for instance a system calling for a mean load of 150 kilowatts, representing a moderate-sized system of some twenty running cars.

Under the typical conditions mentioned above, the maximum load which may from time to time be demanded will rise as high as 450 kilowatts. To deal with this, therefore, in the first instance it will be necessary to instal a plant capable of generating this output, or no less than 300 kilowatts, over and above the mean load, and on taking the cost of a complete installed plant at £30 per kilowatt, which I think will be admitted to be a fair and reasonable figure, this means no less than £9,000 in surplus plant over and above the £4,000 to £5,000 plant which must of necessity be employed to deal with the mean load.

In the second instance, by employing a battery to deal with the demand over and above the mean load, it will require that there should be installed a battery capable of delivering as a maximum 300 kilowatts. The cost of a battery to comply with these conditions would approximate somewhere about £12 per kilowatt, including booster and switchboard arrangement, or an expenditure of £3,600 as and against the £9,000 in the first instance, or a clear saving in capital expenditure of approximately £5,400.

In both the above instances no allowance has been made for spare plant; this must, of course, be provided in both cases, but the necessary amount will be considerably less in the case where the battery is employed.

The above examples apply to the case in which the battery is installed at the power-house. Where the battery

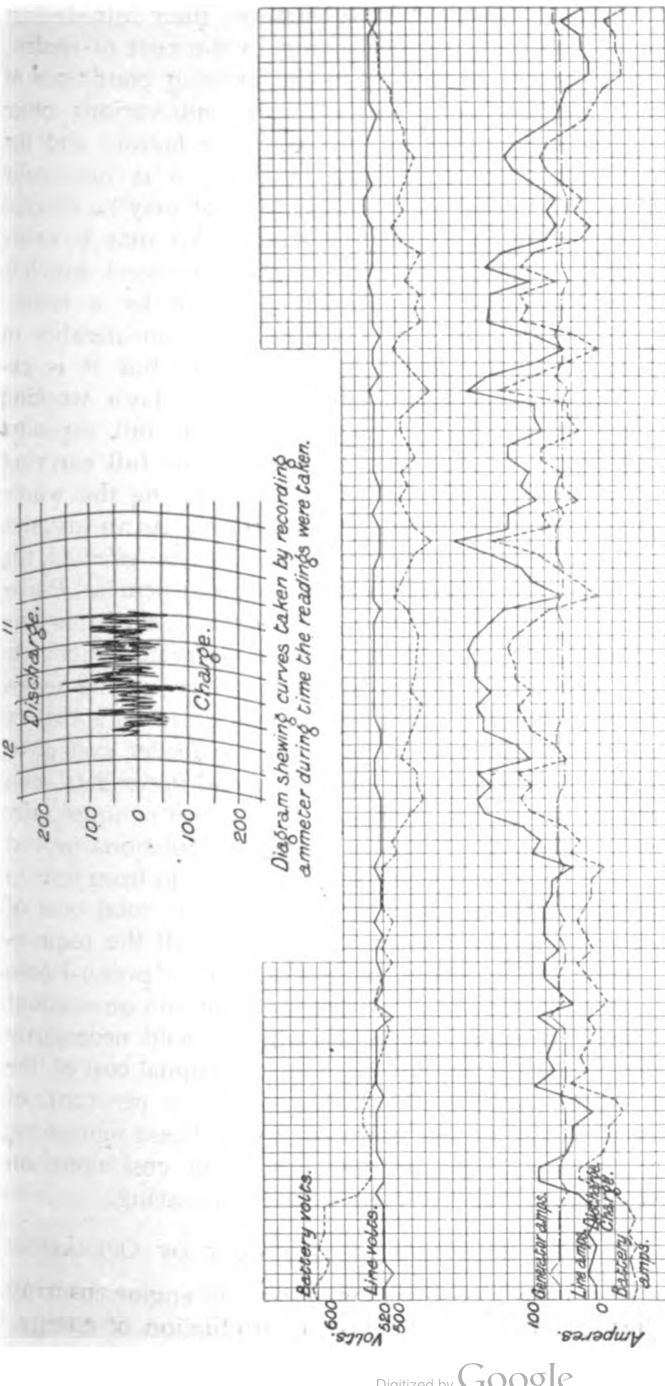

DIAGRAM 7.—Curves from Generator, Battery and Special Booster on a Tramway Load (8 Cars on Line; 100 kw. Shunt-wound Generator; Battery 1 hour Discharge-rate 110 amperes).

or batteries are installed in substations their introduction will effect in addition a great saving in the cost of feeders, varying, of course, according to the existing conditions of the line, distance from power-house, and various other factors. Owing to the number of these factors and the wide variations that may exist in them, it is practically impossible to formulate any idea as to what may be effected in the way of saving, though a rough idea may be easily arrived at if we consider for a moment the work which is usually performed on any traction system by a feeder. This, of course, must necessarily vary considerably in accordance with the traffic upon the line, but it is extremely doubtful if the aggregate of a day's working amounts to more than 10 per cent. of its full capacity. With a battery installed at a substation, the full carrying capacity of the feeder can be employed during the whole of the operating hours of the power-station. As an instance of the enormous saving that may at times be effected, the case of the Union Traction Company's system at Philadelphia is a marked instance. The extension of this line was found to be necessary, and the service practically increased to double. It was found that it would be necessary either to build a new power-house or instal a battery substation, as to attempt to augment the feeder system to the extent that would be demanded would necessitate such an enormous outlay for copper as to render it commercially impossible. The most carefully made calculations proved that the cost of copper alone would amount to from four to five times, excluding the cost of laying, the total cost of battery installation necessary to fully meet all the requirements, while the question of an additional power-house was found to be absolutely out of the question on account of the heavy operating expenses which would necessarily be incurred, apart from the fact that the capital cost of the battery-station was considerably less than 50 per cent. of the estimated cost of the power-station. These figures are sufficient to show how on the question of cost alone on the first outlay a battery is an undoubted saving.

THE SAVING TO BE MADE IN THE COST OF OPERATION is self-evident, the high-load factor on the engine ensuring the highest economy in the cost of production of energy,

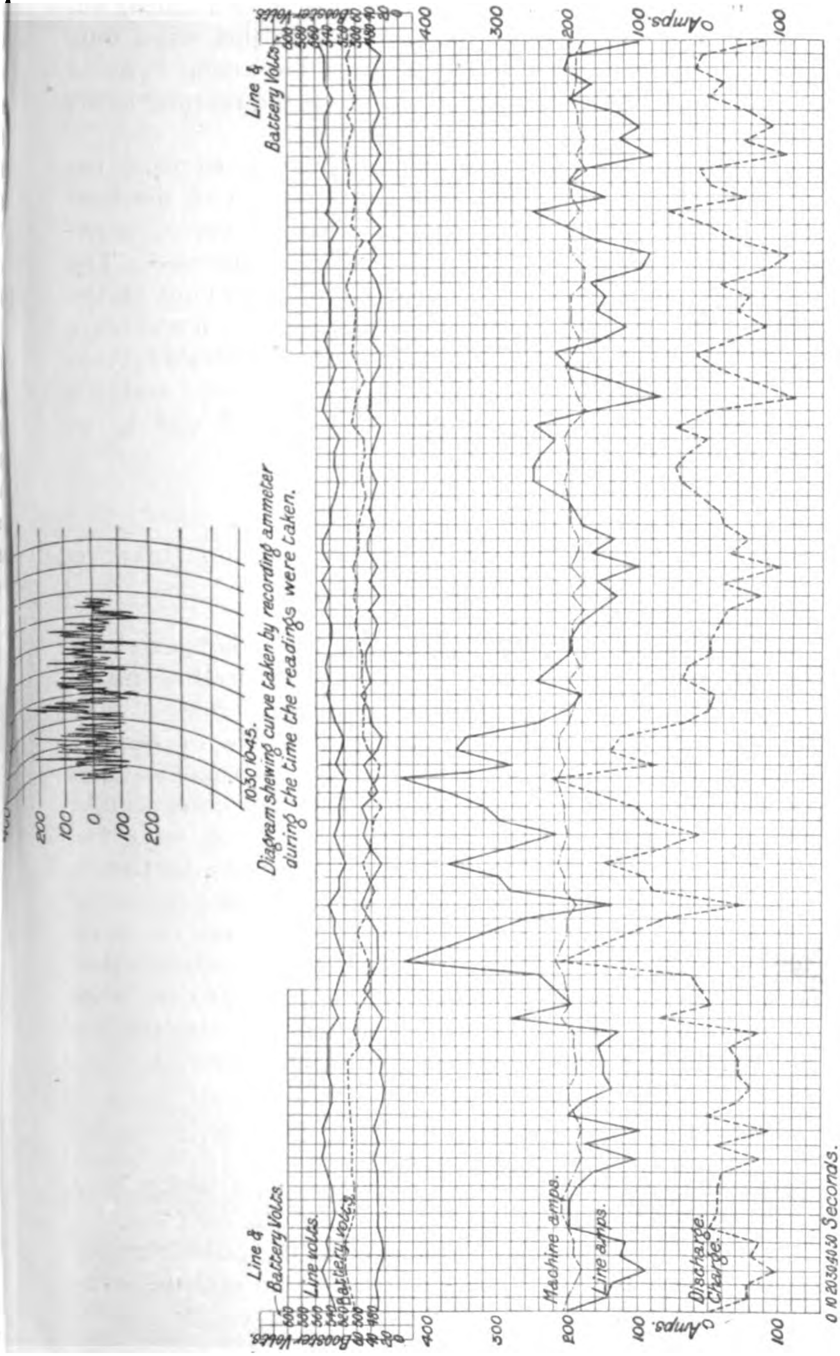

DIAGRAM 8.—Curves from Generator, Battery, and Special Booster on a Tramway Load (20 Cars on Line; 125 kw. Shunt-wound Generator; Battery 1 hour Rate of Discharge 450 amperes).

and if it is possible to reduce, as before mentioned, our coal consumption 75 per cent. almost on this score only the cost would be justified, apart from the saving in many instances of an entire shift and the decreased running hours of machinery.

The question will naturally arise here as to what the battery losses will amount to on that portion of the load that is dealt with by the battery. These are very considerably less than are generally estimated to be the case. The actual result of four consecutive months' working of the plant from which the curves on Diagrams Nos. 8 and 9 are obtained show that out of 234,072 units generated, 8,240 were absorbed by the booster, or 3·5 per cent., and the efficiency of used to generated units worked out to 91 per cent.

The next point to consider will be what

Relative Proportion the Battery should Bear to the Station Capacity.

To effectively instal a battery, this is a point requiring careful consideration, and will vary considerably under different existing conditions. As a general rule, it may be taken that the battery should be capable of dealing with from twice the mean load in the case of small stations to half the load at large stations; a very considerable range, it will be noted, due to the fact that with the increase in number of running cars the relative variations of load will decrease, and also to a considerable extent by the size of generators employed in the case of large stations. No more definite rule can well be formulated to deal with the question, each case requiring to be dealt with on its own merits. The question will be further influenced to a considerable degree by the exact

Method of Employing the Battery.

There are several methods of employment, which may generally be divided into two main heads, namely:—

(*a*) Where the battery is employed at the power-station.

(*b*) Where the battery is employed at an outlying sub-station.

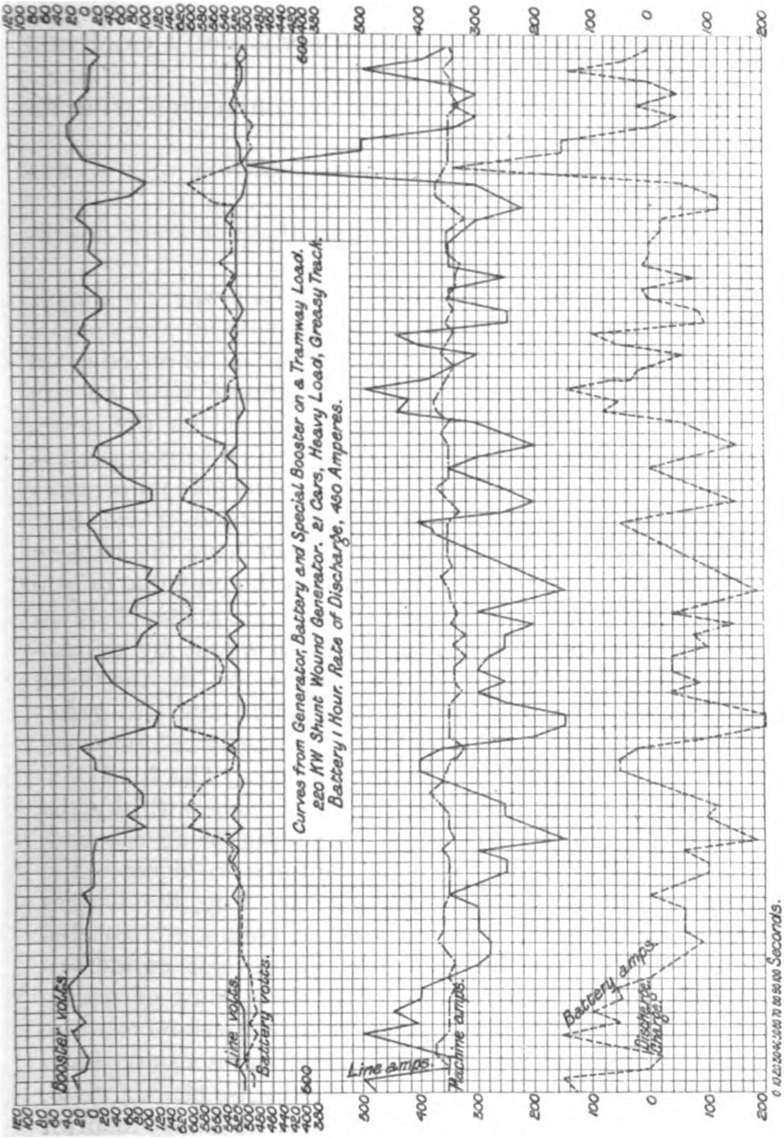
Curves from Generator, Battery and Special Booster on a Tramway Load.
220 KW Shunt Wound Generator. 21 Cars, Heavy Load, Greasy Track.
Battery 1 Hour. Rate of Discharge, 450 Amperes.
Booster volts.
Line volts.
Battery volts.
Line amps.
Machine amps.
Battery amps.
Discharge.
Charge.
Seconds.

DIAGRAM 9.

Each of these two main divisions can be again subdivided into—

First, where the battery is coupled as a whole across the mains or bus-bars;

Second, as the first, but with a portion of it employed as regulating cells;

Third, where it is employed in conjunction with an ordinary booster; and

Fourth, where it is used in conjunction with a differential or reversible booster.

The function of the battery under these different conditions will vary considerably.

Let us, in the first instance, take the case where a simple battery is installed at the power-station without any special apparatus for its control, its two extremities being coupled direct to the bus-bars. Under these conditions a certain portion of the fluctuations of load must fall on the generator, and a certain variation of voltage must be permissible at the bus-bars in order that the battery may take its proportion of the load. This is easily understood if we first consider a condition of no external load, have the battery standing at a potential of 500 volts, and the potential of the generator at 500 volts; it is now very evident that the two will balance and nothing result. If, however, by adjustment of the governors of the engine, or by the field windings of the generator, we so arrange that the generator potential shall rise, then, as can easily be followed, the generator will charge into the battery. The load next comes on the line, which should be dealt with by the generator up to the point of its full output being reached, after which, should the load still continue to increase, the generator voltage should commence to drop, the battery voltage predominate, and the battery commence to discharge to line. As the load falls the reverse conditions will take place. This method of working must of necessity require a certain amount of voltage variation on the bus-bars, and consequently on the line, and it also requires a very careful predetermination of the precise characteristic of the generator. The results generally obtained cannot be deemed to be satisfactory, though greatly improving matters as compared with the case in which no battery is employed, they are nevertheless far behind what can be obtained with other methods of employment.

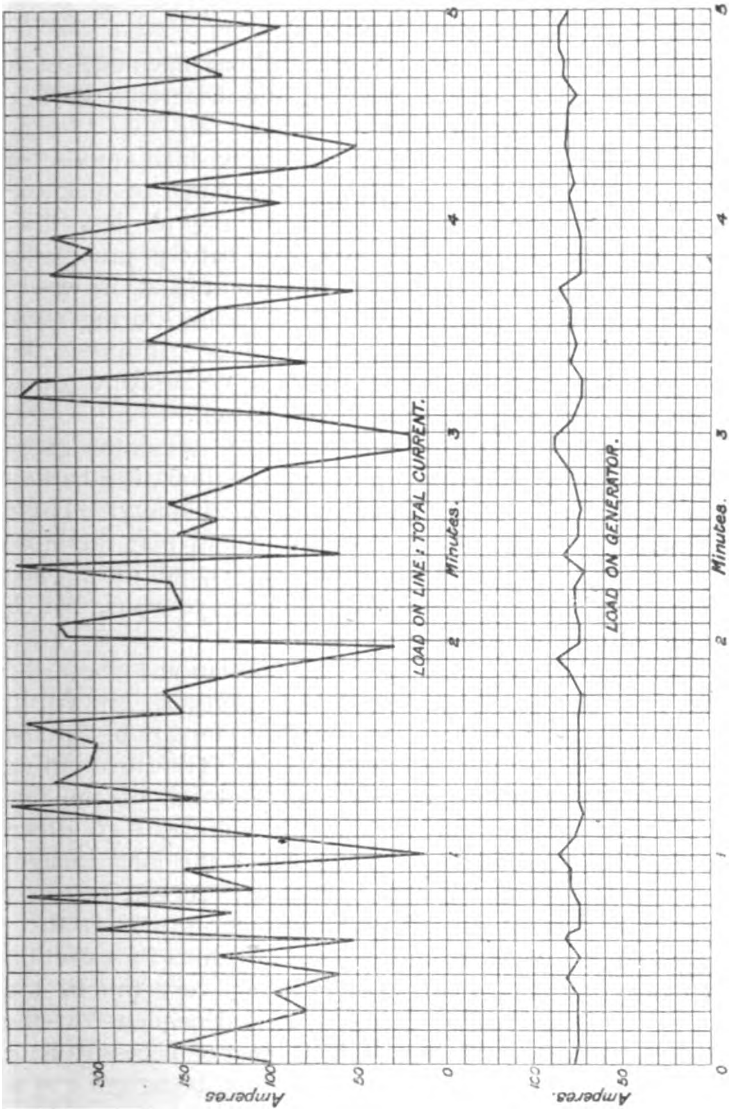

DIAGRAM 10.—Load Diagram.

This system has, it is to be regretted, been rather widely adopted not only at home, but also abroad, and the modicum of success obtained with it has, I am afraid, resulted in rather discouraging and disappointing those adopting it.

Diagram No. 3 shows the general arrangement of a battery employed on this method, and Diagrams Nos. 4 and 11 the results obtained.

From these will be noted the extremely small amount of work done by the battery and the wide range of machine load—in No. 4 the machine load varying no less than from 160 to 210 amperes, and the battery practically getting no charge at all, with the result that it would either have to be charged by special means during slack time or after running hours. Under these conditions the battery is of little real value, and is certainly working under very bad working conditions to itself.

Diagram No. 11 shows very much the same, the generator practically following the load throughout, the battery being induced to assert itself very occasionally. These readings were taken soon after charge, and may therefore be assumed to be working under best conditions. The voltage curve shows a variation of over 50 volts, which cannot be deemed satisfactory.

The method of adoption at the substations, where the battery is simply placed across the mains, as shown in Diagram No. 5, is possibly the simplest adaptation, but the results are as equivalently unsatisfactory. Here everything does and must depend on the rise and fall of the line voltage. At times of heavy load the volts will go down and the battery discharges, while when the load is light the voltage rises and the battery charges. As can be easily gathered, the result cannot give satisfaction; nor is there any possible chance, within reasonable limits of variation of voltage, of the battery ever doing very much, the operation of the battery being entirely dependent on the variations of the line voltage, which must of necessity have a wide range to ensure any effectual work being got out of the battery. To be perfect, a storage battery should be without internal resistance, so that, however great the current passing through it, the fall or rise of volts across the terminals due to that current, whether charging or

discharging, should be negligible. Unfortunately no storage battery has been made which show these qualities, nor, I am sorry to say, does it appear likely there ever will be.

In quite a number of cases that have come to my personal knowledge where batteries have been installed under these conditions, they simply lie little less than "dead" on the line. A recent instance I have in mind, where a battery which had been installed with adequate boosting arrangements at a power-station was, on being replaced at the power-station by a considerably larger battery, itself removed to an outlying substation, and employed there in this way pending arrangements for boosting. The battery which has a one-hour discharge rate of 150 amperes, under its old methods of working frequently discharged up to 175 amperes and over, while under the new conditions it has never been known to exceed 40 amperes. Diagram No. 4 also demonstrates the same poor result. The battery in this case has a one-hour discharge rate of 190 amperes, and it will be noticed that the highest point ever reached is only 90, and that quite an exception. It is certainly not worth while installing a battery under these conditions if an effectual result is desired from it, and, further, the working conditions are distinctly detrimental to the battery.

In the second method mentioned above, namely, the adoption of regulating cells, various attempts have been made from time to time to increase the effectiveness of batteries installed either at power-stations or at outlying substations, by employing a portion of them as regulating cells. Automatic apparatus for cutting cells in or out as the line potential falls or rises with variation of load, has in several instances been adopted; the general result, however, has been a conspicuous failure. The method is an extremely expensive one, particularly in the case of large batteries necessitating the use of a great number of costly regulating leads and expensive switch-gear to keep in order. It is almost impossible to charge the regulating cells correctly, and hence they deteriorate rapidly and become a constant source of trouble, the suddenness and rapidity of the current fluctuations being such as to make it impossible to follow them, at any rate by any automatic switches

that have so far been devised. If anything at all in this direction is to be accomplished, I am of opinion that it will be by means of some automatic and interlocking rocking apparatus with mercury contacts, but I am very much afraid that the strongest feature about it will be the pyrotechnic display which will in all likelihood accompany its operations.

The third system, namely, the employment in conjunction with an ordinary booster, has met with a certain amount of success.

In this method the battery is more usually employed as a store or reservoir of energy, the charging being effected for definite periods by means of the booster current being added to that of the line, or more generally special feeder, and the battery discharged by being placed across the line, either with or without regulating cells, at times of very heavy load, when the generators are running, or when the load is as light as not to justify the generators being kept running. Under both these conditions a battery can often be employed with great advantage and material saving of running expenses, but the work generally is heavy on the battery, and very liable to abuse. Except to meet very special circumstances, this system has no special advantage to recommend it.

The fourth method, namely, when employed in conjunction with a differential or reversible booster, is undoubtedly, at any rate as far as our present knowledge is concerned, the correct and proper way of operating a battery on a traction system, irrespective of whether it is installed at the power-house or at an outlying station. Diagram No. 6 shows the general arrangement of plant at a power-station. The arrangement may be thus shortly described :—

In series with the battery is connected the booster, which is provided with a variable field. The field is automatically controlled by the battery pressure, and the booster pressure varies exactly as the battery pressure departs from the desired constant, so that the pressure across the terminals of the battery and booster combined is constant, the whole being perfectly automatic and controlled absolutely by the windings of the booster and the battery pressure.

In the case of a battery and booster of this description employed on a traction system, or any system where the

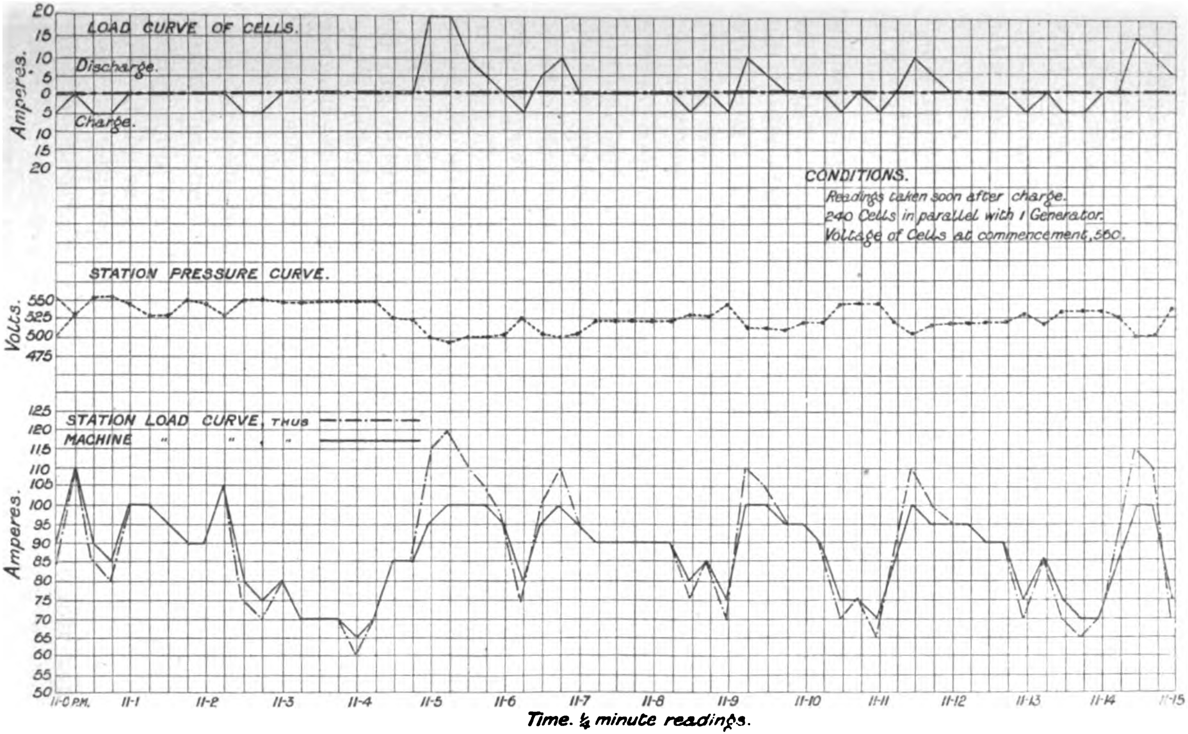

DIAGRAM 11.—Curves from Generator and Battery without Booster on Tramway Load. Hour Discharge-rate of Battery, 190 amperes.

load is of a rapidly varying character, the battery controlled by the booster serves to take charge of practically the whole variation, whether above or below the normal or mean load, so that the generator works at practically a steady constant load, the difference between the load and the mean, charging into the battery when the line load falls below the mean, and the battery discharging to line whenever the load exceeds the mean. The generator load will naturally be adjusted to be the mean load required to generate the total average output for the usual period of work.

The general features of this arrangement which commend it as being of special value on a tramway system, may be summed up as follows :—

The first cars run out in the morning, and under the precisely similar conditions of energy supply can be worked entirely from the battery, thus obviating the necessity of starting up the power-station for a few early workmen cars some two or three hours before the general load comes on. During the day the battery will be intermittently charging and discharging, the output of the generator or generators being fixed at such an amount that at the predetermined time of shutting down the battery is fully charged. Should the battery be found not to be in its normal state of charge at shutting down, owing to any abnormal demand, the running time can be prolonged, or the loss compensated for, by slightly increasing the generator output the next day; *vice versâ*, if the battery is overcharged, the output may be decreased. The power-station can be shut down on the heavy load falling off, the remaining late cars being run, as the early morning ones, off the battery only. The advantages of working a plant under these conditions are self-evident.

Working at full constant load, the greatest possible economy can be ensured, the actual running hours shortened, and the most uneconomical and unprofitable hours in every sense of the whole day's work avoided. The minimum of plant running necessary for operating the load, wear and tear on the plant generally will be much less, the load on the generators being practically constant; ordinary shunt-wound machines may be used, though the system works as perfectly with compound-wound machines. The switching-gear is of the simplest description, and is reduced

to a minimum, and the whole arrangement absolutely automatically controls itself.

The general working conditions are most favourable to the life of the battery, the latter being kept constantly fully charged, and immediately charged after discharge.

Diagrams Nos. 7, 8, and 9 give some highly interesting curves obtained under different conditions with a tramway system, in which a battery and booster of this description form part of the power-station equipment. The steady generator load is particularly noteworthy, also the range of the total load curve, the variations of which are taken almost entirely by the battery.

Diagrams Nos. 8 and 9, further, are interesting examples of how a load on the same system may vary, due principally to conditions of traffic and weather, practically the same number of cars running in both cases, while the mean load differs widely.

The actual recorder curves—which I regret to say I have not been able to get reproduced—show very clearly the result which can be obtained on a system equipped with a battery and booster. The two most interesting curves are the two bottom ones on each sheet, namely, those showing the battery voltage and the line voltage—the difference between the two is entirely due to the booster. Employing a battery without a booster, the battery voltage, and probably rather worse, would represent the line voltage. The different curves on each of these sheets were taken simultaneously.

The battery must, of course, be properly adapted for the work it has to perform. It must be capable of being charged at very high rates without injury, and of the minimum possible internal resistance, so as to ensure the least possible range of voltage. These conditions are best met with in plates of the Planté type, and with such the battery losses amount to but a small percentage of the total load.

As can readily be understood, a great deal depends on the design and construction of the booster necessary to properly carry out these functions. Up to quite recently the differential or reversible booster has been practically unknown, and those machines which did exist can scarcely be looked upon as being either highly effective or highly

efficient. The extended adoption of batteries in connection with power plants has, however, created a demand, and of late considerable attention has been paid to the construction of this type of machine, and various methods and arrangements have been designed to meet the necessary requirement; in many instances the results have left very much to be desired, and in cases where the working may have been passable, the efficiency has been such as to preclude their being considered. There is very little doubt but that the most successful machine that has so far been introduced is that for which Mr. J. S. Highfield is responsible. By this machine all the functions above mentioned are attained to a remarkable degree, and with the highest efficiency. The booster is a distinctly novel departure, in that it consists of three distinct machines, namely, a motor generator or booster and exciting controller, by means of which the unwieldy and waste windings, which have prevailed in all other machines, and which have seriously impaired their efficiency, have been avoided.

The function of the third machine is to control the excitation of the booster, and runs in direct opposition to the battery current; by this means the requisite field reversals are obtained.

Operating a traction or power system with a machine of this type practically results in the battery becoming, as it should do,

The Real Regulator of the System.

The extent to which a battery should control or regulate a system is an interesting factor. Personally, I am of opinion that it should take the sole and entire charge and control of the whole, even to the extent of not excluding the engine—in other words the engine should be run without a governor on a constant steam pressure and constant valve admission. This will doubtless by many be considered to be a bold departure, but I am convinced myself that the best curves on the accompanying diagrams, or any hitherto obtained, might be still better under these circumstances, and that the small generator variations that do occur are due to the governor attempting to follow the load instead of leaving it entirely to the battery to compensate for, as

should be the case. The abolition of the governor on a power-station engine is the consummation of an ideal devoutly hoped for, but I am certain in many instances, with a proper equipment of battery and booster it is perfectly feasible.

In closing this paper, I must express my thanks for the kind assistance rendered me, both by information and curves, by Mr. McMahon, of Bispham, and Mr. Highfield, of St. Helens.

"TEST-ROOM METHODS OF ALTERNATE-CURRENT MEASUREMENT" AND "USE OF THE DIFFERENTIAL GALVANOMETER."

FURTHER REPLIES TO REMARKS COMMUNICATED IN THE DISCUSSION ON THESE PAPERS

By Mr. ALBERT CAMPBELL and Mr. C. W. S. CRAWLEY.

Mr. A. CAMPBELL (*added July 3rd*): As Mr. Drysdale has amplified his original remarks and communicated a further criticism, I should like to add a few more words of reply to what he says. He is at great pains to calculate the maximum errors in the three-voltmeter method with a power-factor of 0·1, but he does not notice that I never suggested that my modification of that method should be used directly for such low power-factors, which, I may remark, are somewhat exceptional in practice.

In further answer to the question of the possible slowness of readings on a damped electrostatic voltmeter, I have found that at least four or five readings can be got in one minute, and I may mention that I have used a "switch over" method with perfect success on a very unsteady circuit from an alternator run by a gas-engine. With regard to wattmeters, I fully appreciate the admirable design of Mr. Drysdale's instrument, and I should be delighted to see it on the market at the price of an electrostatic voltmeter. I am much interested also in Mr. Addenbrooke's beautifully sensitive instrument. But I think that Mr. Drysdale begs the whole question by assuming that a wattmeter which seems theoretically well designed will work correctly with low power-factors (and any wave-forms). Actual tests with alternating current under the most extreme working conditions seem to me absolutely essential.

From Mr. Alexander Russell's interesting remarks upon my first Appendix, I fear I condensed that part of my paper a great deal too much. As Mr. Russell has really added an important corollary to my theorem, I will try to state the matter a little more definitely as follows:—

THEOREM.—*If two purely alternating uniform magnetic fields, A and B, of any wave-forms and equal effective values be inclined to one another at an angle $\pi - \phi$, where $\cos \phi$ is their power-factor, then the effective value of the resultant (rotary) field will be constant in all directions in any plane containing the directions of A and B.*

COROLLARY (Mr. Russell's).—*It is always possible to incline two alternating fields B and C to one another at such an angle ψ that the effective voltage induced in a search-coil shall be constant for all positions into which the coil is turned around an axis perpendicular to the directions of B and C, provided that B and C each separately induce equal maximum effective voltages in the search-coil.*

It should be remarked that in general ψ is *not* equal to $\pi - \phi$.

It is the above theorem that I have applied to Dr. Arnò's phase-meter, in which the search-coil is connected with an electrodynamometer. Mr. Mather has pointed out to me that the current in the electrodynamometer would not necessarily be a proper measure of the field perpendicular to the search-coil. The proper conditions can be secured, however, by making the time-constant of the search-coil circuit high (see *Phil Mag.*, p. 271, Sept. 1896).

I am glad to find that Professor Callendar's experience corroborates mine as to the accuracy and value of thermal methods. I knew that he and others had employed hot-wire bridge methods of measurement, but I was not aware that he had also devised a thermal regulator similar to mine, and I understand that this is the first occasion on which he has published his method.

As to Mr. Gillespie's remarks on Method 7, I may mention that I arranged that method specially for the Shallenberger Watt-hour Meters, and I believe they were the first commercial meters (in this country) that were systematically adjusted with inductive as well as non-inductive loads.

Mr. C. W. S. CRAWLEY: Mr. Foster mentions a—to me—novel use of the differential galvanometer, viz., as a standard of capacity. The idea is pretty and I hope to try it shortly. As he suggests, it would make a nice examination question, and there would probably be a lack of monotony about the answers.

Had Mr. Fisher been present at the meeting he would have seen that I showed both a Kelvin and a d'Arsonval differential galvanometer. For most work I prefer the Kelvin instrument. I know there is a scare just now about tramway disturbances, but I think it is a good deal exaggerated. In the Kelvin instrument I showed, the 0·1 ampere through 1 ohm that he mentions will give 45 divisions for a difference of 0·01 per cent., so tramways must be very energetic to introduce a practical error or even appreciable inconvenience. In the d'Arsonval form there is a little shift of zero, but not enough to prevent easy and accurate working. The d'Arsonval is, of course, not so sensitive as the Kelvin instrument.

As to the merits of the two methods, I only took to the differential galvanometer when I found the potentiometer wanting for a particular test; and, having once tried it, never used the potentiometer for low resistance work again. It was only then that I saw my way to having a potentiometer made without a slide-wire to get damaged; for Mr. Fisher's "obvious remedy" to "ignore small boys and half-bricks" (I said wear and students—but no matter) does not appeal to me. I do not feel happy in ignoring possible scources of error or using any slide-wire for accurate work that I have not kept under lock and key.

Mr. Fisher's summing up also appears open to criticism. He says "in the differential galvanometer method you are dependent on delicate apparatus and forces, in the potentiometer one you have only mechanical excellence to contend with." Now the "apparatus and forces"—the galvo and E.M.F.s—are common to both methods and equally delicate in both cases. The potentiometer method requires in addition "mechanical excellence," *i.e.*, an expensive slide-wire board. The accuracy obtainable in the latter case being limited by that of the slide wire; in the former solely by the knowledge of the value of the standards used. The figures he gives are quite satisfactory as far as they go—0·1 per cent.—but I should never have thought of suggesting that Mr. Fisher could not get right to that by potentiometer or any other method.

NEWCASTLE LOCAL SECTION.

Abstract of Paper read at Meeting of Section, February 11th, 1901.

NOTES ON WIRING RULES.

By F. BROADBENT, Member.

Hackneyed though the subject of Wiring Rules may be, there is still great need, in the interests of Standardisation, to emphasise the necessity of a uniform set of rules, satisfactory alike to the consumer, the contractor, the fire office, and the supply companies.

From all sides the cry is raised: "Standardise at all costs; let not wholesale scrapping deter you; standardisation means repetition, and repetition means cheap production; heed not that repetition begets tradesmen rather than professionals, slaves instead of free men." And there is some danger of standardisation being set us as a fetish, the effect of which will be to stifle invention and scientific research, and which, instead of hastening, will impede the march of progress. May the time be far distant when "wholesale scrapping" shall be looked upon as a virtue, or when the true spirit of progress and research shall be sacrificed upon the mean altar of a cast-iron standard.

Between such a state of things and that in which there is absolutely no recognised standard, there exists a wide gulf, both extremes being equally unsatisfactory. No right-thinking man can or will deny that uniformity of general principles, that is to say, method, is absolutely essential for the successful and economic prosecution of any industry, and that Anarchy is just as fatal in the industrial as in the social sphere.

Probably no industry in this kingdom was ever so hampered by rules and regulations as is the electrical industry at the present time, and the people who were loudest in their complaints as to the stringency of the original B.O.T. regulations, are, now that these restrictions have been somewhat removed, the worst offenders. Rules,

however stringent, can be tolerated if it be possible to work to them, for at most they but raise prices. It is the want of uniformity that is so exasperating and irritating.

The Phœnix Fire Office, in 1882, issued a set of "Rules for Electric Light Installations," and nearly every other fire office of importance has since issued rules of its own. The other companies appear to have made their rules as unlike the Phœnix set as possible, with the result that, when an electric installation has to be carried out in premises insured with two or three companies, it requires a very large amount of ingenuity on the part of the contractor to comply with the conflicting conditions. As though this were not enough for the contractors to bear, it has become the fashion now for every station engineer to invent a set of rules of his own, differing as much as possible from any other known rules, which, besides worrying the contractor, may deter many a householder from becoming a "consumer," as he must naturally think electricity is very dangerous if it requires such an array of rules and regulations. Why station engineers issue rules which they cannot enforce is somewhat a puzzle. Glasgow and Manchester possess powers to enforce their rules, and other municipalities have been urged to seek similar powers. Let them not do so, by sandwiching an innocent-looking clause into a Workmen's Dwelling Act, or the like, but, until some definite set of approved rules is agreed upon, let them do so in such a manner that manufacturers and contractors may oppose any proposal that would give unlimited power to station engineers to impose such harassing and iniquitous rules as some of those now existing.

As already mentioned, the subject of the standardisation of wiring rules is no new one. In the beginning of 1899, three papers were read on the subject before a meeting of this Institution. The one by Mr. Pigg went very fully into the diversity in the requirements of the various rules then existing, but emphasised more particularly the variations touching the question of the insulation resistance of an installation. The paper by Mr. Wordingham was a plea for "a definite standard set of rules, by which every one will agree to be bound;" whilst Mr. Crompton's short paper was written to urge the adoption of the revised rules issued by the Institution of Electrical Engineers

in 1897. At the end of a two nights' debate, the following resolution was unanimously and enthusiastically carried :—"That this meeting is of opinion that the Institution should take such steps as it thinks best to secure uniformity in rules, by pressing on supply companies, municipal engineers, and fire offices the advantages of adopting rules to be drawn up by the Institution, based on the present ones, as a standard, with such modifications only as local conditions may necessitate." It was not unreasonable to suppose that before two years had expired, not only would the new rules have been issued, but that they would have been in general use throughout the country. Instead of this, however, rules multiply and become more and more dissimilar.

In introducing his paper Mr. Wordingham remarked: "It is to the interests of contractors to have a definite set of regulations drawn up, and central station engineers are equally interested in having uniform rules." He then went on to say: "It is no use talking about a thing and saying it is very desirable, if the people who talk are not really determined to do each one his best to arrive at the result he advocates. We must all be prepared to give up something if we are to secure uniformity, and although it is rather mortifying, perhaps, to give up a pet regulation, I think it behoves everybody concerned to do so, if in this way a uniform standard can be arrived at." (This Journal, vol. 28, p. 176.) The charm of the remark lies in the fact that the Manchester Regulations (issued October, 1899), contained, in addition to 17 conditions relating to supply, no less than 62 rules relating to wiring and fittings, which are distinctly stated to be additional and not in substitution of the ordinary wiring rules. When it is stated that the Phœnix Fire Office Rules number 43, and those of the Liverpool, London, and Globe, for *ordinary* risks, number 117, it means that for ordinary installation work on the Manchester mains, and in accordance with the rules of the two companies mentioned, one must be conversant with considerably over 200 wiring rules, to say nothing of those of the Institution of Electrical Engineers.

Owing to the variety and extent of the work now undertaken by large manufacturers and contracting firms or companies, it is necessary for superintending engineers to keep in touch with all the principal requirements both

of Fire Insurance, Supply Companies, and municipalities, in order that the fittings and installation accessories shall comply as far as possible with them.

The writer has attempted, for the purposes of this paper, to tabulate those rules to which he has occasion most frequently to refer. The rules of Bradford and one or two other important stations are omitted, as they are at present undergoing revision. Those tabulated, however, will probably suffice to impress upon the members present the great need that exists in this particular department for that "wholesale scrapping" process that some people think so desirable in our manufactories.

Comparing these rules with themselves and each other, it is soon evident how hopeless it is to attempt to standardise anything until the rules themselves have been standardised. Take the Phœnix Rules first.

After reading carefully the 39 pages of which the rules consist, one has no idea of what would satisfy the technical officer of the Phœnix Company, and not one electrician in 100 could define exactly what is and is not in accordance with these rules. They abound in exceptions and contradictions. In the 43 rules there are over 50 exceptions or cases requiring special permission. On one page we read that all conductors must be of copper, and in the following pages that copper is not obligatory in all cases, although there is nothing to indicate under what circumstances any other material may be used. As regards enclosing conductors, the first part of rule 5 reads that conductors in non-hazardous risks should be enclosed in "iron or other approved metal tubes" (by which one understands that iron *is* approved), or in other approved fireproof tubes, or in wood casing. In the next paragraph we are told that "No tube of *any* kind will be allowed that is not approved by the technical office of the fire office," which gives the impression that tubes generally are not approved: whilst in a later paragraph of the same rule we find that "a number of conductors may be placed in a single iron or steel tube." Rule 7, p. 11, says that all hidden conductors "*must* be enclosed in approved metal tubing, or other approved tubing, or wood casing." This would be the most definite rule in the book if it ended there, but it is rendered useless by the characteristic addition: "unless in the opinion of

the technical adviser of the fire office tubing or wood casing would not be desirable." When the various kinds of tubing and casing are not permissible it is not obvious what else could be used to enclose a conductor. The above examples are not specially chosen, but are among the first rules in the book, and form a fair sample of the whole.

For the purposes of this paper it will be more convenient to compare the rules and requirements of various companies or corporations on specific subjects rather than comment upon the whole of one set of rules after another.

The question as to condition of supply does not much affect the wiring contractor, except that he is sometimes asked by his customer to carry on the negotiations with the Supply Company, and for this purpose it is useful for him to know to what distance the Supply Company bring in their mains free. This information has been put in the general column of the schedule appended.

Switches.—On almost every supply the consumer must provide a double pole switch, that is to say, a switch on both poles of the mains, but not in every case a cut-out or fuse. In some rules a fuse is specified, *e.g.*, in the rules of the Manchester, Sunderland, Blackpool, York, and many others, but in others no mention is made of a cut-out to be fixed by the contractor. It is quite possible, however, that in all these cases the Supply Company would ask for one to be fixed. In other rules, however, it is clearly stated that the consumer must on no account provide a cut-out, and among these may be named West Hartlepool, Carlisle, Grimsby, and Chelsea. Some rules specify the position in which this fuse shall be fixed in reference to the main switch, and in some cases this is fixed on the supply side of the main switch instead of on the consumer's side. This, surely, is not as it should be, as it is necessary in replacing a fuse to replace this in live wires which cannot be cut off, and in the case of 400/500 volts supply there is some risk of shock being felt. Not content with specifying a double pole switch, some companies go into detail of manufacture and specify that the two switches should be rigidly joined together by a connecting link, and also specify the lengths of break and the distance between the poles. In the case of Glasgow the length

of break is given for switches and fuses on 250 and 500 volts circuits for currents ranging from 5 to 250 amperes. The figures are given in the schedule and may possibly comply with existing standard switches and cut-outs.

CONDUCTORS, CASING, ETC.

Turning now to the requirements, *re* conductors, there is a certain amount of diversity, not only as regards the insulation resistance, but also as regards the smallest and largest size of conductor permissible, and also the smallest section of conductor that may be used. In almost every case copper is specified, as it is probably considered that no case would arise in which aluminium or iron might be used. This may be true so far as interior wiring of houses is concerned, but for works using overhead wires, there is, surely, no objection either to aluminium or to iron from the supply company's point of view.

As regards the insulation resistance required for cables, this varies in different rules from 300 megs. per mile, to 2,500 for vulcanised rubber. In some cases other materials may be used by special permission. Lead-covered conductors are advocated for damp situations in many towns, but are objected to in others, notably in Edinburgh. Full particulars are embodied in the schedule, so need not be further enlarged upon. Tynemouth Corporation specify not only the size, the insulation, the density, and the maximum drop to the farthest lamp, but also specify that two different colours of wire must be used, viz., red for positive, and black for negative, though what this has to do with the Corporation is a mystery.

As regards the sizes of solid and stranded conductors to be used, the Institution of Electrical Engineers' rule is adopted by a large number of supply companies and municipalities, but not by all, whilst some companies make no mention of this whatever. And rightly so: it has nothing whatever to do with them. Glasgow forms an exception to the above rule, as on its circuit *all* conductors must be stranded, and it is preferred that not more than 100 amperes pass down any single conductor. Many companies and municipalities also specify the current density to be used, notwithstanding the fact that in very

many cases they point out that their rules are to be taken, not as a substitute, but in addition, to those of the fire insurance companies and of the Institution of Electrical Engineers. It is well known that the Phœnix Company have from their first edition specified a current density of 1,000 amperes per square inch, and whilst this is a fairly convenient rule to work to, it is not pretended by any one that it is at all scientific. The rules of the Institution of Electrical Engineers specify the temperature rise permissible in conductors, and give a table of currents and sizes corresponding with this rule. The London, Liverpool, and Globe Insurance Company, who have certainly the best rules in existence, both from a practical and a scientific standpoint, and rules, as to the interpretation of which there is very little doubt, do not specify the temperature rise for conductors, but give a varying density, viz., for incandescent work, 1,500 amperes per square inch up to 10 amperes; 1,000 amperes per square inch from 10 to 100 amperes; and 800 amperes per square inch for currents of over 100 amperes; whereas for arc lamps, motors, heating, etc., the density is less, viz., 1,000 amperes per square inch up to 50 amperes, and 800 amperes per square inch for currents over 50 amperes. The reason for this is that there is the possiblility of the current varying, and occasionally becoming considerably more than the normal. Very few lists of rules appear to take note of this fact.

A very large number of the rules of the supply companies and municipalities follow the Phœnix rules, whilst advising their customers to work to those of the Institution of Electrical Engineers, *i.e.*, they specify that the density must not exceed 1,000 amperes per square inch, which contradicts the Institution rule. Sunderland and Tynemouth Corporations, the City of London, and Brush, stipulate that not more than 2 volts drop must be lost to the farthest lamp, whilst Chelsea, and probably some others, limit the drop to 1 volt, a point which surely has nothing to do with the supply authorities.

On the subject of enclosing conductors, most of the rules permit either wood casing or tubing, although in some cases preference is expressed for tubing. Reference is made in many rules as to blocking out of casing on

damp walls, but the distances to which this is to be blocked out varies in different localities. In Manchester, $\frac{3}{4}$ inch is necessary; whereas in Sunderland, Liverpool, and elsewhere, $\frac{1}{2}$ inch is considered sufficient. Sunderland rules specify that all casing must have two coats of shellac varnish before use, and where out of sight the wires are to be run in wood or earthenware casings, cement troughing, or other approved insulated tubes or conductors. It will be observed that neither gas-pipe nor Simplex steel pipe will comply with this rule. In Blackpool casing is not recommended under any circumstances, and is only allowed for face work. The same applies to the rules of Reading Supply Company. Not only is the nature of the casing or tubing specified by supply companies, but some even go further than this, and specify the sort of nails which must be used to fix the casing. Liverpool may be instanced as one of the companies that go to this extent, and it will be found that besides asking for casing to be painted, add that it may be fixed to walls by steel nails of oval section.

An iniquitous rule, which one is sorry to see in the Sunderland list, is found also in the rules of Blackpool and Salford, to the effect that the Corporation has the right to demand that the contractor shall open joints, take down casing, etc., for inspection, and reinstate it at his own cost. The contractor is certainly entitled to compensation if no fault be found.

Distribution.—The first people to systematise wiring were the ship lighting contractors. When a ship once leaves port, all repairs, whether jointing a damaged wire or merely replacing a fuse, must be carried out by the engineers, many of whom may have never been shipmates with electric light before, and have to find out for themselves all they need to know. It soon became recognised that the simple tree system, with its fuses dotted up and down the ship like so many limpets, and often quite inaccessible during a voyage, was not the ideal system.

A distribution system was devised in which the main circuit cables from the dynamo room fed distributing fuse boxes placed in accessible positions, and from which circuits of about 5 amperes were taken, no reduction in

the size of the branch conductors being made between the distributing points and the lamps. Five-ampere circuits were fixed upon because a 7/21½ stranded cable or its equivalent is a very convenient size to use, and as the average length of run between the distributing board and the lights is not great, the extra cost of the wire is more than counterbalanced by convenience, the reduction of waste, and the saving in individual fuses (as none are fixed after leaving the distributing centres). This system was soon adopted for land installations, but modified of course to suit the different conditions, as it would be very expensive in the majority of cases to use so large a conductor for single lamps. The average supply station engineer, however, is trying to insist upon circuits, not of the carrying capacity of 7/21½ conductor, but of 1½ ampere circuits in many cases, and even less than 1 ampere in the case of Edinburgh.

A glance down the column headed "Branch Switches, Fuses, and Circuits" shows that whilst Manchester ask for 2½ amperes circuits, Glasgow 3 amperes, a very large proportion of the other towns put the limit at ten 8 c.p. lamps, which means circuits of less than 1½ amperes in a 230-volt system, which is now very largely used and certainly is the pressure of many of the stations which have adapted this ridiculous rule. The Tynemouth rules read that no branch circuit should carry more than 5 amperes, or 10 lamps. The candle-power of the lamps is not specified, so in a shop using high candle-power lamps, 5 ampere circuits may be run, whilst in a house using 8 c.p. lamps no circuit would carry more than 1½ amperes. It should not be overlooked, however, that according to the Phœnix rules, no lamps must be considered less than 16 c.p.

On the subject of branch switches and cut-outs, and small wiring accessories such as ceiling roses, wall sockets, and the like, there is an appalling variety of opinion. Manufacturers of such appliances must often be at their wits' end to decide what to stock and what to scrap, and it is scandalous that they should have to make so many varieties of almost every article to meet the fads of station engineers, when it would pay them far better and enable them to reduce prices if they could standardise more, and cut down the number of stock patterns.

In some towns double pole fuses, that is positive and negative under one cover, are prohibited, whilst in other places they are permitted. The Liverpool, London and Globe Insurance Company do not like them, and will not permit them on circuits of over 130 volts, nor in mills, warehouses, or the like. No exception can be taken to this rule, as D.P. fuses certainly ought to be abolished, and, with the growth of the distribution system of wiring, the use of isolated fuses will naturally become less and less. One still sees distributing boards fitted up with a dozen or so round type fuses with fluted brass covers, but the tendency is rightly towards the use of distributing boxes containing clip type fuses mounted on slate or china. These, however, raise other points, viz., that in Blackpool slate is not permitted as an insulator, whilst in many other places, including York, Grimsby, Carlisle, and West Hartlepool, fuses with metallic covers are not allowed. Under the same set of rules the main switches must also be provided with non-conducting covers. It is not obvious why main switches should be treated differently in this respect to branch switches; if a metal cover is good enough for a "tumbler" switch, in which the working parts are very close to the cover, it is equally good for a main switch in which there is a greater distance between the covers and the working parts. In Salford and Blackpool, however, sockets, fuses, and switches must have covers of vitrite or porcelain, or an equivalent, whilst in Tynemouth switches in damp places have both covers and handles of non-conducting material. Here is one of those interesting cases in which the contractor is between the station engineer and the Board of Trade. The station engineer says that he will not permit a main switch with a metallic cover, whilst the Board of Trade requires that upon any circuit at a pressure of over 250 volts, all lines (an expression now generally understood to cover all switches and terminals) shall be protected by a metallic cover efficiently connected to earth.

It may not be inopportune to mention here that the Board of Trade require that the two pairs of a three-wire system carrying over 250 volts pressure shall be brought into a building at points six feet apart and kept quite distinct throughout the building. It will be very interesting to hear what kind of treble pole switch, as specified by

Tynemouth and some other rules, would satisfy this condition, and if the rule as to the coupling together of the two main switches is insisted on in Glasgow and elsewhere under such conditions, as it would not be a very simple matter to couple two switches together if they are placed six feet apart. Glasgow, however, appears to be quite outside the range of the Board of Trade requirements; they are not only 20 volts above the Board of Trade limit, but have a special rule that if two double pole switches are used, one on each side of the three-wire system, they must not be less, and presumably need not be more, than one foot apart. The same occurs in the Edinburgh rules. There is certainly some obscurity as to the real meaning of the Board of Trade rule. The word "lines" may be taken to mean "cables" only, but as the cable ends must be brought into the switches the lines cannot be wholly enclosed in metallic casing unless the switches and every other accessory in connection with the cables are also protected in the same way. Many station engineers interpret the rules in this way, although they do not specifically mention it in their rules. Almost, if not all the London companies insist on both switches and fuses on circuits of 400 volts and upwards being enclosed in iron boxes, whilst the Bristol Corporation, in their special rules for continuous current, demand that all cables, switches, fuses, and motors shall be enclosed in strong metal cases connected to earth.

This digression was caused by the rules against non-metallic covers, and we must retrace our steps a little to the further consideration of small accessories. It would seem to be somewhat outside the province of the Supply Company to specify the position or precise arrangement of individual switches, but the Tynemouth Corporation rules that: "Tumbler switches to be ON when the handle is DOWNWARDS." Now this is a matter that neither affects the fire risk nor the conditions of supply, but is an argument for uniformity, and on that account the rule is not without merit. But other people may also have views on this subject, and, if the North-Eastern Railway Company wire any of their stations or premises and become customers of the Tynemouth Corporation, the Corporation engineer will probably find all the tumbler switches arranged upside down. The convenient rule of the North-Eastern Railway

Company is: Switch up, light up; switch down, light down."

The Institution of Electrical Engineers did a very questionable thing in specifying ventilated fuse boxes. Rule 10 reads that the covers of all fuse boxes should be efficiently ventilated, so as to avoid fracture by the sudden expansion of the air within them at the time the fuse melts, the covers being arranged to catch and retain the fused metal. Ceiling roses are not mentioned under this rule, but logically a ceiling rose containing a fuse should comply with the same conditions as a fuse which is not a ceiling rose. Ceiling rose covers have been known to burst on the fuse blowing owing to a short circuit in the flexible or in the lampholder. This might very easily start a fire in a cotton spinning or weaving mill, where the ceiling roses are fixed immediately over the looms or mules. The fault of this rule, however, is in specifying "ventilation" instead of demanding that the fuse cover shall not burst due to the blowing of the fuse. What has happened is this: not only do station engineers refuse to pass non-ventilated fuses, but some manufacturing firms have seized the opportunity to patent a ventilated fuse, which, according to their travellers' stories, is the only fuse that will not burst, and at the same time will not permit the fused metal to escape. A rival firm has a fuse that is not ventilated, and does not require ventilation, and cannot be made to burst, explaining that a fuse does not burst by expansion due to the fuse blowing, but by the expansion and heat due to the arc started inside the fuse box by the tin vapour. If all terminals are embedded in porcelain in such a way as to leave the minimum surface exposed, an arc will not start and the fuse cover will not burst, Q.E.D. This, then, is one of the minor results due to a too precise laying down of the law relating to fuses.

Another of the contractors' worries is that, not content with specifying the nature of the fuse box itself, some engineers have fads on the kind of fuse metal to be used. In Tynemouth, the fuse wire preferred is "fine copper strand," and must have a clear length of 1½ in.; whilst in Chelsea a branch fuse must consist of a single strand of pure tin, not larger than No. 28 S.W.G., preferably soldered to copper terminals—not an easy thing to do, by

the way—and should lie in a fuse chamber lined with plaster of Paris, length of break 1¼ in. Glasgow and Edinburgh specify tin, preferably with copper ends; Bury *prefers* fine copper strand.

It is unnecessary to refer in detail to all the minor differences that occur in the various rules, most of these may be seen in the schedule. Attention may be called, however, to the requirements as regards ceiling roses; under some conditions they must contain fuses, under others they must not, whilst Mr. Pigg, in his paper already referred to, mentioned that he had heard but had not seen a specification which called for double pole fuses in each ceiling rose. The specification certainly did exist, and the installation was carried out under the writer's superintendence.

Motors, etc.

More important, however, are the differences in the requirements concerning motors and their regulation, the earthing of motors and heating appliances, and the insulation resistance required for a complete installation. According to the Institution rules, dynamos and motors starting and regulating resistances, and switches, must be spaced 12 inches horizontally and 4 feet vertically from woodwork or inflammable material. This rule is copied verbatim into the Glasgow rules, and is, of course, understood to be embodied in all those rules which are stated to be additional to those of the Institution. Notwithstanding this, in many of the rules the figures are varied in accordance with the fancy of the engineer for the time being. Blackpool rules, after stating distinctly that the rules of the Institution are to be strictly adhered to, give the distance as 18 inches, and this distance would presumably pass the Corporation Inspector, who, however, would prefer to see the resistances hung outside of the building! The Edinburgh rule is to the effect that resistances must not be fixed *on or near* woodwork, but should be fixed to brick or stone walls, and be so mounted that they stand 6 inches from the wall. Surely there is no risk of a resistance burning a brick or stone wall down. The Liverpool Corporation rules stipulate that resistances shall be 6 inches from woodwork, whilst the Reading Supply Company specify 18 inches,

although the Institution and fire office rules are also to be complied with.

Arc lamp resistances are more leniently dealt with by the Institution, although it is not obvious why they should be considered less dangerous than motor resistances. Probably the argument is that motor resistances are generally larger than those for arc lamps. On the other hand, arc lamp resistances are frequently grouped in one place, whereas a motor starting resistance is generally fixed singly alongside the motor, so if this be the argument it is not a very strong one. Whatever the reason may be, the fact remains that, according to the Institution of Electrical Engineers' rules, arc lamp resistances should be 6 inches from woodwork horizontally and 2 feet vertically, which is just half the requirements for dynamcs, motors, or their resistances. Now it is pertinent to ask why the Institution should be more stringent upon a purely fire risk question than are any of the fire office rules. Surely the fire offices, with all their experience, have fixed a safe limit. Now what are the fire office rules on this subject. The Phœnix rules stipulate that any woodwork near a dynamo, motor, or resistance should be protected by fireproof material, but no distance is named. The Liverpool, London and Globe Insurance Company prefer that resistances should be on a brick or stone wall, isolated from inflammable material, no distance being stated. The London and Lancashire Fire Insurance Company, whilst giving the same distances as the Institution rules, recognise the absurdity and practical impossibility of the latter; they realise that in practice neither a dynamo nor a motor can be raised 4 feet above the floor (if the latter happen to be wood), except in rare cases, so the word "unprotected" is inserted, making the rule read common-sense. Thus: "Dynamo to be placed 4 feet vertically from any *unprotected* woodwork." But the obvious course is to protect it, so the next rule reads: "Dynamos to be placed on a sheet of metal of sufficient size to protect the floor when fixed on a non-fireproof floor." The same rule applies to *all* resistances, whether for motors or arc lamps. These, rules, whilst being based on those of the Institution, are amplified and made more definite.

The Hand-in-Hand Fire Office requires that dynamos shall not be placed within 12 inches of any *unprotected*

the way—and should lie in a fuse chamber lined with plaster of Paris, length of break 1¼ in. Glasgow and Edinburgh specify tin, preferably with copper ends; Bury *prefers* fine copper strand.

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More important, however, are the differences in the requirements concerning motors and their regulation, the earthing of motors and heating appliances, and the insulation resistance required for a complete installation. According to the Institution rules, dynamos and motors starting and regulating resistances, and switches, must be spaced 12 inches horizontally and 4 feet vertically from woodwork or inflammable material. This rule is copied verbatim into the Glasgow rules, and is, of course, understood to be embodied in all those rules which are stated to be additional to those of the Institution. Notwithstanding this, in many of the rules the figures are varied in accordance with the fancy of the engineer for the time being. Blackpool rules, after stating distinctly that the rules of the Institution are to be strictly adhered to, give the distance as 18 inches, and this distance would presumably pass the Corporation Inspector, who, however, would prefer to see the resistances hung outside of the building! The Edinburgh rule is to the effect that resistances must not be fixed *on or near* woodwork, but should be fixed to brick or stone walls, and be so mounted that they stand 6 inches from the wall. Surely there is no risk of a resistance burning a brick or stone wall down. The Liverpool Corporation rules stipulate that resistances shall be 6 inches from woodwork, whilst the Reading Supply Company specify 18 inches,

although the Institution and fire office rules are also to be complied with.

Arc lamp resistances are more leniently dealt with by the Institution, although it is not obvious why they should be considered less dangerous than motor resistances. Probably the argument is that motor resistances are generally larger than those for arc lamps. On the other hand, arc lamp resistances are frequently grouped in one place, whereas a motor starting resistance is generally fixed singly alongside the motor, so if this be the argument it is not a very strong one. Whatever the reason may be, the fact remains that, according to the Institution of Electrical Engineers' rules, arc lamp resistances should be 6 inches from woodwork horizontally and 2 feet vertically, which is just half the requirements for dynamos, motors, or their resistances. Now it is pertinent to ask why the Institution should be more stringent upon a purely fire risk question than are any of the fire office rules. Surely the fire offices, with all their experience, have fixed a safe limit. Now what are the fire office rules on this subject. The Phœnix rules stipulate that any woodwork near a dynamo, motor, or resistance should be protected by fireproof material, but no distance is named. The Liverpool, London and Globe Insurance Company prefer that resistances should be on a brick or stone wall, isolated from inflammable material, no distance being stated. The London and Lancashire Fire Insurance Company, whilst giving the same distances as the Institution rules, recognise the absurdity and practical impossibility of the latter; they realise that in practice neither a dynamo nor a motor can be raised 4 feet above the floor (if the latter happen to be wood), except in rare cases, so the word "unprotected" is inserted, making the rule read common-sense. Thus: "Dynamo to be placed 4 feet vertically from any *unprotected* woodwork." But the obvious course is to protect it, so the next rule reads: "Dynamos to be placed on a sheet of metal of sufficient size to protect the floor when fixed on a non-fireproof floor." The same rule applies to *all* resistances, whether for motors or arc lamps. These, rules, whilst being based on those of the Institution, are amplified and made more definite.

The Hand-in-Hand Fire Office requires that dynamos shall not be placed within 12 inches of any *unprotected*

combustible material *other than their seating*, thus recognising what apparently the Institution forgot, viz., that a dynamo could not be fixed in mid-air, but must have a seating of some kind. The same rule applies to resistances. The Royal Insurance Company's rule on the subject is practically the same as that of the London and Lancashire Company, and these are the only rules the writer has seen which give diagrams of connections, and photographs of apparatus to illustrate and amplify the text.

It will be seen from the foregoing remarks how diverse and unpractical are the requirements both of the Institution and Supply rules, and how very wide of the mark they are in dealing with simple questions of fire risk. What could be more absurd than the rule that all motor resistances should be on brick or stone walls, except the suggestion that they should be placed "outside of the building." Imagine for a moment a large printing establishment, employing upwards of 100 motors, each provided with a starting switch, and separate regulating switch. It is necessary that the starting and controlling switches should be near the machines, and, assuming the switches to have on the average 10 steps, it would be necessary, if the resistances are placed on the walls, to run at least 2,000 connecting wires between the machines and the walls. Apart from the practical difficulties involved, the fire risk from 2,000 wires would have also to be considered. In Glasgow and Edinburgh only four wires are allowed on one tube, so that in addition to the tube carrying the supply wires, there would be at least 5 other tubes radiating from each machine to the sides of the building, or say about 600 tubes altogether.

Another rule, made only to be broken, is that which limits the temperature of the resistance coils of starting switches and arc lamps to 212 degrees Fahr., "even if left continuously in use." Now a starting resistance never is left continuously in use, unless it is designed to act also as a regulating resistance. Why, therefore, should it be designed to meet conditions that will never occur, or why should a consumer be forced to pay double the necessary price for a starting switch? Starting switches are generally so designed that it is impossible to leave them in an intermediate position, that is to say, in a position in which a current could pass through the starting coils. And, it is

safe to say, that any of the regular patterns of starting resistances, of which there are many thousands in use, would burn out if the normal motor current were passed through for say 10 minutes, and most of them would burn out in less than three minutes. Not only are starting resistances not designed for continuously carrying the current, but the same applies to the contact plates of the switch, and it would be illogical to increase the current-carrying capacity of the one and not the other. What the rule amounts to, therefore, is, that all starting switches and resistances should be large enough to serve as speed regulators, which would practically double the cost, and be provided with abnormally large resistances even for speed regulators. Many people seem to lose sight of the fact that the function of a resistance coil is to dissipate energy in the form of heat, and that it would be, if not impossible, exceedingly inconvenient to provide space in most cases for the enormous coils that would be required if low temperatures are insisted upon. Why! the temperature of *unprotected* steam pipes and connections in Central Generating Stations is very considerably higher than is permissible for *protected* resistance coils in the same room by this rule.

In connection with motor work there are quite a number of rules that need standardising. First is the question of the maximum starting current permissible. It is apparent from the rules that the distributing mains in many towns are cut so fine that any current over 5 amperes suddenly switched on to one circuit is sufficient to disturb the pressure in neighbouring circuits. It does not seem quite fair to the motor user that he should have to pay for complicated and expensive apparatus for the sole purpose of enabling the suppliers to cut down capital outlay in cables for lighting purposes. If switching on or off the full motor current causes a disturbance in the neighbouring lighting circuits, surely it is the business of the supply authorities to lay down separate mains for power purposes. Many of them specify that separate circuits shall be run for motors and lighting *inside* the consumers' premises, a matter quite outside their province, yet, in addition to this, they impose vexatious restrictions on the motor user to enable themselves to use the same supply circuits for both motors and lighting. But to come back to the want of

uniformity in the requirements. These vary from a starting current not exceeding the normal full-load current on the City of London mains, down through various stages to a starting current not exceeding 5 amperes on the Glasgow and some other towns' mains. Nor are the rules always consistent even in the same district. On the Chelsea supply, a 3 H.P. motor may, on starting, exceed its full-load current of 25 per cent., say 16½ amperes. On the same supply, if a motor exceed 3 H.P., its starting current must not exceed 10 amperes, nor increase in steps exceeding 5 amperes each. On the Manchester Supply, no motor must take more than 10 amperes when first switched on, nor increase in steps exceeding 10 amperes. On the same circuit, a 10-ampere arc lamp may, on striking, take 18 amperes, and a 15-ampere arc 27 amperes, whilst an arc requiring normally more than 15 amperes must have a graduated starting resistance limiting the starting current to 15 amperes, and any additional current to 10-ampere steps. In Manchester, therefore, the extraordinary condition exists that a motor, no matter how large, must not take a starting current of more than, roughly, one-third of the current permitted to a 15-ampere arc lamp, and a 10-ampere lamp may take a larger starting current than a 20-ampere one. In Glasgow the starting current must not exceed 5 amperes nor increase in more than 5-ampere steps; in Carlisle and other towns using the same set of rules the starting current must not exceed 5 amperes, and the additional steps must not cause disturbance to the lighting circuits. Many rules permit 10 amperes starting current with the same subsequent conditions as the last named. A fair proportion of the rules call for a mechanical device or overload cut-off to prevent too rapid starting. Any ordinary overload device would fail to pass the Manchester test of pushing the starting switch suddenly over all the contacts to "full on," as the current will considerably exceed the limit before the inertia of the knock-off permits the switch to break circuit; nothing, therefore, but a slow motion gear will meet the case. But, when all the above conditions have been complied with, nothing can prevent the motor current, during normal working conditions, from continually varying through far wider ranges than 10 amperes. A motor driving a printing machine will not only suddenly fall from

full load to zero, but will at times actually fall beyond this and act as a dynamo and put current back into the mains, owing to the inertia of the machine connected with it. A motor driving a pair of cotton spinning mules will vary instantly from light load, say 10 amperes up to 200 amperes, and then quickly fall to 40 amperes, and then back to light load, and will repeat this cycle every few seconds. A motor driving a heavy planing machine may vary between 30 and 90 amperes every few seconds, yet in both the latter cases the starting up could comply even with the Glasgow conditions, as the motor would start on a loose pulley. Or, take the case of a newspaper printing machine absorbing 50 H.P. It must be possible to stop the machine instantly from any part of the machine, and it is not obvious why starting should be more detrimental to neighbouring lamps than stopping. To the uninitiated it would seem that the opposite is the case.

The Board of Trade rules are too well known to need repetition in full here. As has already been mentioned, on circuits of 250 volts and upwards all lines forming the connections to motors, or otherwise, must be completely enclosed in metallic casing as far as practicable, the casing being efficiently connected with earth. Each motor to have a switch under the control of the attendant by means of which all pressure can be cut off from the motor or from any apparatus in connection with it. Fuses on each pole to be provided. All switches and cut-outs to be so enclosed as to prevent danger from shock or fire. The above is a brief summary of the Board of Trade requirements, and it is interesting to observe how these apparently simple rules have been interpreted by different people. To take the enclosing and earthing first. Whilst in some localities it has been found that the ordinary steel tubing, known as "Simplex" or "Crown tubing," meets all the requirements for enclosing cables without any special bonding of joints, in others it is required that each joint should be bonded or that an earthed bare copper wire shall be enclosed throughout the full length of the tube, whilst in other places nothing but screwed gas-piping is passed. Then, as to the method of earthing. In Bristol all casings and frames, whether of motors, wires, switches, or resistances, must be earthed with a wire capable of carrying

ten times the fusing current of the main fuse. In Bury, Glasgow, etc., the earthing wire must be equal in section to the conductor; in Carlisle, Grimsby, West Hartlepool, York, and other towns which have adopted the same set of rules, all motors are to be efficiently *insulated* from earth. This rule may refer to the windings of the motors and not to the frames, but nothing further is specified. In Edinburgh, the frames of all motors, whether 230 or 460 volts, must be earthed. In Manchester, all motors, whether on the 100, 200, or 400-volt circuits, are to be connected to earth with a copper conductor, equal in section to the motor conductor, but need not exceed 10 square millimetres. Resistances on 400-volt circuits to have metallic covers connected to earth. In Reading, the switches as well as the wire on 400-volt circuits are to be enclosed in earthed metallic sheathing. In Sunderland, the frames of 400-volt motors must be earthed by a cable not less than 7/18, quite regardless of the size of the motor. It would appear from the foregoing, that the almost general feeling among station engineers is that the Board of Trade rule as to enclosing and earthing applies to cables, switches, and resistance frames, as well as to motors, but, Glasgow again forms the notable exception, and insists on all resistance frames being *insulated* from earth.

The various other points in connection with motor work would occupy too much time to specify in detail. It might, however, be noted that some of the London companies specify that motors must be shunt wound. This is certainly not the best for a very variable load, even from the Supply Company's point of view; whilst some specify that the shunt shall be broken on an inductive resistance, which is contrary to ordinary practice. The County of London, and Brush, are exceptional in asking for a single pole switch only, which is to be on the positive pole which forms the inner wire of the Company's mains. Possibly the reason for this is that the outer is earthed, and, if this be so, it is interesting to note, as the rules stipulate that all work must be carried out in accordance with the rules of the fire offices, that the Phœnix Office has a rule to this effect, "Switches and cut-outs should always act on the internal (or live) wire when the system is earthed," followed by the characteristic and amusing saving clause, "but switches and fuses may be

required on the other wire should the technical adviser to the fire office consider it advisable." The Supply Company further requires a switch and fuse on each main, near the point of supply, and, on the same subject, one of the Phœnix rules on page 15 reads, " when one main of a high-tension system is earthed, that main need *not* have a cut-out." Then, of course, the saving clause comes in, " unless required by the technical adviser of the fire office." On turning to page 28, another rule reads, " if one pole of a supply system be 'earthed,' each conductor *must* still have a switch and cut-out at its point of entrance into the consumers' premises," then, with really praiseworthy consistency, the usual exception, " unless permission to the contrary be given, etc."

Upon the question of earthing, Manchester has exceptional rules. Every radiator, including stoves, hot plates, ovens and cooking apparatus generally, must be earthed. In the case of portable apparatus this means a triple flexible conductor, and special 3 connection plugs and sockets. Electric kettles or other portable heaters must stand at least 6 inches above a table or anything combustible, and if electric irons and curling tongs come within the definition, electric laundry work is impossible in the Manchester district, and ladies must still depend upon the uncertain spirit lamp or gas jet to heat their tongs.

Without referring to the question of insulation resistance, upon which subject Mr. Pigg has dealt so exhaustively, the writer hopes he has said enough to awaken in the members some sense of the great need that exists for one definite and comprehensive set of rules, rules which shall be self-luminous, needing no interpreter, rules that the wayfaring man, though a' jerry wireman, can understand and work to, and rules therefore that may be enforced.

Newcastle has ever been in the van in the March of Progress, and we of this section of the Institution must see to it that we worthily uphold the tradition. We must aim at being foremost among the local sections in everything that makes for the advancement either of the commercial or scientific interests of the industry with which we are all so proud, and justly proud, to be associated.

If, by our voice and influence, we can hasten the day when uniformity shall reign, even only in the matter of

wiring rules, we shall have done not a little to justify our existence.

Mr. Turnbull. Mr. C. TURNBULL: The writer of the paper appears to think that standardisation may mean stagnation. I think, however, that there is little to fear from this, as standardisation really means that change is only made in the interests of progress instead of in a haphazard fashion. The business firms who standardise most are almost always the most progressive. I will first of all answer some of the criticisms on the Tynemouth rules. The writer of the paper objects to the rule that switches should be on the red wire. My reason for this is to ensure that switches shall be on the live wire of our three-wire system, so that if a switch be off, the fitting connected to it will be dead. The rule is convenient to remember—red wire danger wire; black wire neutral or dead wire. With regard to the writer's idea that the station has no right to object to a heavy drop of pressure in a consumer's premises, he here exposes himself to the suggestion that he is backing up the "jerry-wirer." Certainly the station has a great deal to do with the proper wiring of consumer's premises. I knew of one case, for instance, where a large shop was wired on the heavy-drop system, and the owner of this shop never ceased to write strong letters to the engineer of the station. He also created discontent amongst other consumers and prospective consumers, and I am not sure if eventually he did not put down his own plant. Furthermore, too little copper means heating and danger of fire. The consumer must be protected in the present state of matters, and the station engineer is the only one who can protect him. With regard to the insulating of switch handles, I have known cases where you could not switch on the light without getting a shock.

With the spirit of the paper, however, I am in entire sympathy. I think it would be a very excellent thing if we could have in house-wiring something akin to Lloyds' rules in shipping. Some three or four specifications could be drawn up to suit all classes of work, from cases where only the very highest quality was required, down to cases where work of the cheapest kind consistent with safety was aimed at. When a wiring firm contracted to wire a building, they could state on which specification they were tendering, so that every one would be on equality. Laws need administrators, and to carry out this idea properly it would be necessary to have a laboratory—preferably in charge of the Institution—which would examine and pass all suitable fittings, giving them a certificate that they could be used under a certain specification. I think that the expense might be easily met by contributions from the various stations, and also by fees from the manufacturers for testing fittings. Jerry-wiring firms wonld be put on the black list if necessary. All disputes could be referred to this department. By means such as this, I think that standardisation and progress could be assured.

Mr. Moir. Mr. ALEX. MOIR: Before referring to a matter dealt with in the Fire Office rules, I would like to support Mr. Turnbull in his contention that the use of distinctive colours for positive and negative leads is a real advantage. Certainly, whatever may be the practice in electric

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many cases they point out that their rules are to be taken, not as a substitute, but in addition, to those of the fire insurance companies and of the Institution of Electrical Engineers. It is well known that the Phœnix Company have from their first edition specified a current density of 1,000 amperes per square inch, and whilst this is a fairly convenient rule to work to, it is not pretended by any one that it is at all scientific. The rules of the Institution of Electrical Engineers specify the temperature rise permissible in conductors, and give a table of currents and sizes corresponding with this rule. The London, Liverpool, and Globe Insurance Company, who have certainly the best rules in existence, both from a practical and a scientific standpoint, and rules, as to the interpretation of which there is very little doubt, do not specify the temperature rise for conductors, but give a varying density, viz., for incandescent work, 1,500 amperes per square inch up to 10 amperes; 1,000 amperes per square inch from 10 to 100 amperes; and 800 amperes per square inch for currents of over 100 amperes; whereas for arc lamps, motors, heating, etc., the density is less, viz., 1,000 amperes per square inch up to 50 amperes, and 800 amperes per square inch for currents over 50 amperes. The reason for this is that there is the possiblility of the current varying, and occasionally becoming considerably more than the normal. Very few lists of rules appear to take note of this fact.

A very large number of the rules of the supply companies and municipalities follow the Phœnix rules, whilst advising their customers to work to those of the Institution of Electrical Engineers, *i.e.*, they specify that the density must not exceed 1,000 amperes per square inch, which contradicts the Institution rule. Sunderland and Tynemouth Corporations, the City of London, and Brush, stipulate that not more than 2 volts drop must be lost to the farthest lamp, whilst Chelsea, and probably some others, limit the drop to 1 volt, a point which surely has nothing to do with the supply authorities.

On the subject of enclosing conductors, most of the rules permit either wood casing or tubing, although in some cases preference is expressed for tubing. Reference is made in many rules as to blocking out of casing on

damp walls, but the distances to which this is to be blocked out varies in different localities. In Manchester, ¾ inch is necessary; whereas in Sunderland, Liverpool, and elsewhere, ½ inch is considered sufficient. Sunderland rules specify that all casing must have two coats of shellac varnish before use, and where out of sight the wires are to be run in wood or earthenware casings, cement troughing, or other approved insulated tubes or conductors. It will be observed that neither gas-pipe nor Simplex steel pipe will comply with this rule. In Blackpool casing is not recommended under any circumstances, and is only allowed for face work. The same applies to the rules of Reading Supply Company. Not only is the nature of the casing or tubing specified by supply companies, but some even go further than this, and specify the sort of nails which must be used to fix the casing. Liverpool may be instanced as one of the companies that go to this extent, and it will be found that besides asking for casing to be painted, add that it may be fixed to walls by steel nails of oval section.

An iniquitous rule, which one is sorry to see in the Sunderland list, is found also in the rules of Blackpool and Salford, to the effect that the Corporation has the right to demand that the contractor shall open joints, take down casing, etc., for inspection, and reinstate it at his own cost. The contractor is certainly entitled to compensation if no fault be found.

Distribution.—The first people to systematise wiring were the ship lighting contractors. When a ship once leaves port, all repairs, whether jointing a damaged wire or merely replacing a fuse, must be carried out by the engineers, many of whom may have never been shipmates with electric light before, and have to find out for themselves all they need to know. It soon became recognised that the simple tree system, with its fuses dotted up and down the ship like so many limpets, and often quite inaccessible during a voyage, was not the ideal system.

A distribution system was devised in which the main circuit cables from the dynamo room fed distributing fuse boxes placed in accessible positions, and from which circuits of about 5 amperes were taken, no reduction in

the size of the branch conductors being made between the distributing points and the lamps. Five-ampere circuits were fixed upon because a 7/21½ stranded cable or its equivalent is a very convenient size to use, and as the average length of run between the distributing board and the lights is not great, the extra cost of the wire is more than counterbalanced by convenience, the reduction of waste, and the saving in individual fuses (as none are fixed after leaving the distributing centres). This system was soon adopted for land installations, but modified of course to suit the different conditions, as it would be very expensive in the majority of cases to use so large a conductor for single lamps. The average supply station engineer, however, is trying to insist upon circuits, not of the carrying capacity of 7/21½ conductor, but of 1½ ampere circuits in many cases, and even less than 1 ampere in the case of Edinburgh.

A glance down the column headed "Branch Switches, Fuses, and Circuits" shows that whilst Manchester ask for 2½ amperes circuits, Glasgow 3 amperes, a very large proportion of the other towns put the limit at ten 8 c.p. lamps, which means circuits of less than 1½ amperes in a 230-volt system, which is now very largely used and certainly is the pressure of many of the stations which have adapted this ridiculous rule. The Tynemouth rules read that no branch circuit should carry more than 5 amperes, or 10 lamps. The candle-power of the lamps is not specified, so in a shop using high candle-power lamps, 5 ampere circuits may be run, whilst in a house using 8 c.p. lamps no circuit would carry more than 1½ amperes. It should not be overlooked, however, that according to the Phœnix rules, no lamps must be considered less than 16 c.p.

On the subject of branch switches and cut-outs, and small wiring accessories such as ceiling roses, wall sockets, and the like, there is an appalling variety of opinion. Manufacturers of such appliances must often be at their wits' end to decide what to stock and what to scrap, and it is scandalous that they should have to make so many varieties of almost every article to meet the fads of station engineers, when it would pay them far better and enable them to reduce prices if they could standardise more, and cut down the number of stock patterns.

In some towns double pole fuses, that is positive and negative under one cover, are prohibited, whilst in other places they are permitted. The Liverpool, London and Globe Insurance Company do not like them, and will not permit them on circuits of over 130 volts, nor in mills, warehouses, or the like. No exception can be taken to this rule, as D.P. fuses certainly ought to be abolished, and, with the growth of the distribution system of wiring, the use of isolated fuses will naturally become less and less. One still sees distributing boards fitted up with a dozen or so round type fuses with fluted brass covers, but the tendency is rightly towards the use of distributing boxes containing clip type fuses mounted on slate or china. These, however, raise other points, viz., that in Blackpool slate is not permitted as an insulator, whilst in many other places, including York, Grimsby, Carlisle, and West Hartlepool, fuses with metallic covers are not allowed. Under the same set of rules the main switches must also be provided with non-conducting covers. It is not obvious why main switches should be treated differently in this respect to branch switches; if a metal cover is good enough for a "tumbler" switch, in which the working parts are very close to the cover, it is equally good for a main switch in which there is a greater distance between the covers and the working parts. In Salford and Blackpool, however, sockets, fuses, and switches must have covers of vitrite or porcelain, or an equivalent, whilst in Tynemouth switches in damp places have both covers and handles of non-conducting material. Here is one of those interesting cases in which the contractor is between the station engineer and the Board of Trade. The station engineer says that he will not permit a main switch with a metallic cover, whilst the Board of Trade requires that upon any circuit at a pressure of over 250 volts, all lines (an expression now generally understood to cover all switches and terminals) shall be protected by a metallic cover efficiently connected to earth.

It may not be inopportune to mention here that the Board of Trade require that the two pairs of a three-wire system carrying over 250 volts pressure shall be brought into a building at points six feet apart and kept quite distinct throughout the building. It will be very interesting to hear what kind of treble pole switch, as specified by

Tynemouth and some other rules, would satisfy this condition, and if the rule as to the coupling together of the two main switches is insisted on in Glasgow and elsewhere under such conditions, as it would not be a very simple matter to couple two switches together if they are placed six feet apart. Glasgow, however, appears to be quite outside the range of the Board of Trade requirements; they are not only 20 volts above the Board of Trade limit, but have a special rule that if two double pole switches are used, one on each side of the three-wire system, they must not be less, and presumably need not be more, than one foot apart. The same occurs in the Edinburgh rules. There is certainly some obscurity as to the real meaning of the Board of Trade rule. The word "lines" may be taken to mean "cables" only, but as the cable ends must be brought into the switches the lines cannot be wholly enclosed in metallic casing unless the switches and every other accessory in connection with the cables are also protected in the same way. Many station engineers interpret the rules in this way, although they do not specifically mention it in their rules. Almost, if not all the London companies insist on both switches and fuses on circuits of 400 volts and upwards being enclosed in iron boxes, whilst the Bristol Corporation, in their special rules for continuous current, demand that all cables, switches, fuses, and motors shall be enclosed in strong metal cases connected to earth.

This digression was caused by the rules against non-metallic covers, and we must retrace our steps a little to the further consideration of small accessories. It would seem to be somewhat outside the province of the Supply Company to specify the position or precise arrangement of individual switches, but the Tynemouth Corporation rules that: "Tumbler switches to be ON when the handle is DOWNWARDS." Now this is a matter that neither affects the fire risk nor the conditions of supply, but is an argument for uniformity, and on that account the rule is not without merit. But other people may also have views on this subject, and, if the North-Eastern Railway Company wire any of their stations or premises and become customers of the Tynemouth Corporation, the Corporation engineer will probably find all the tumbler switches arranged upside down. The convenient rule of the North-Eastern Railway

Company is: Switch up, light up; switch down, light down."

The Institution of Electrical Engineers did a very questionable thing in specifying ventilated fuse boxes. Rule 10 reads that the covers of all fuse boxes should be efficiently ventilated, so as to avoid fracture by the sudden expansion of the air within them at the time the fuse melts, the covers being arranged to catch and retain the fused metal. Ceiling roses are not mentioned under this rule, but logically a ceiling rose containing a fuse should comply with the same conditions as a fuse which is not a ceiling rose. Ceiling rose covers have been known to burst on the fuse blowing owing to a short circuit in the flexible or in the lampholder. This might very easily start a fire in a cotton spinning or weaving mill, where the ceiling roses are fixed immediately over the looms or mules. The fault of this rule, however, is in specifying "ventilation" instead of demanding that the fuse cover shall not burst due to the blowing of the fuse. What has happened is this: not only do station engineers refuse to pass non-ventilated fuses, but some manufacturing firms have seized the opportunity to patent a ventilated fuse, which, according to their travellers' stories, is the only fuse that will not burst, and at the same time will not permit the fused metal to escape. A rival firm has a fuse that is not ventilated, and does not require ventilation, and cannot be made to burst, explaining that a fuse does not burst by expansion due to the fuse blowing, but by the expansion and heat due to the arc started inside the fuse box by the tin vapour. If all terminals are embedded in porcelain in such a way as to leave the minimum surface exposed, an arc will not start and the fuse cover will not burst, Q.E.D. This, then, is one of the minor results due to a too precise laying down of the law relating to fuses.

Another of the contractors' worries is that, not content with specifying the nature of the fuse box itself, some engineers have fads on the kind of fuse metal to be used. In Tynemouth, the fuse wire preferred is "fine copper strand," and must have a clear length of 1½ in.; whilst in Chelsea a branch fuse must consist of a single strand of pure tin, not larger than No. 28 S.W.G., preferably soldered to copper terminals—not an easy thing to do, by

the way—and should lie in a fuse chamber lined with plaster of Paris, length of break $1\frac{1}{4}$ in. Glasgow and Edinburgh specify tin, preferably with copper ends; Bury *prefers* fine copper strand.

It is unnecessary to refer in detail to all the minor differences that occur in the various rules, most of these may be seen in the schedule. Attention may be called, however, to the requirements as regards ceiling roses; under some conditions they must contain fuses, under others they must not, whilst Mr. Pigg, in his paper already referred to, mentioned that he had heard but had not seen a specification which called for double pole fuses in each ceiling rose. The specification certainly did exist, and the installation was carried out under the writer's superintendence.

Motors, etc.

More important, however, are the differences in the requirements concerning motors and their regulation, the earthing of motors and heating appliances, and the insulation resistance required for a complete installation. According to the Institution rules, dynamos and motors starting and regulating resistances, and switches, must be spaced 12 inches horizontally and 4 feet vertically from woodwork or inflammable material. This rule is copied verbatim into the Glasgow rules, and is, of course, understood to be embodied in all those rules which are stated to be additional to those of the Institution. Notwithstanding this, in many of the rules the figures are varied in accordance with the fancy of the engineer for the time being. Blackpool rules, after stating distinctly that the rules of the Institution are to be strictly adhered to, give the distance as 18 inches, and this distance would presumably pass the Corporation Inspector, who, however, would prefer to see the resistances hung outside of the building! The Edinburgh rule is to the effect that resistances must not be fixed *on or near* woodwork, but should be fixed to brick or stone walls, and be so mounted that they stand 6 inches from the wall. Surely there is no risk of a resistance burning a brick or stone wall down. The Liverpool Corporation rules stipulate that resistances shall be 6 inches from woodwork, whilst the Reading Supply Company specify 18 inches,

although the Institution and fire office rules are also to be complied with.

Arc lamp resistances are more leniently dealt with by the Institution, although it is not obvious why they should be considered less dangerous than motor resistances. Probably the argument is that motor resistances are generally larger than those for arc lamps. On the other hand, arc lamp resistances are frequently grouped in one place, whereas a motor starting resistance is generally fixed singly alongside the motor, so if this be the argument it is not a very strong one. Whatever the reason may be, the fact remains that, according to the Institution of Electrical Engineers' rules, arc lamp resistances should be 6 inches from woodwork horizontally and 2 feet vertically, which is just half the requirements for dynamos, motors, or their resistances. Now it is pertinent to ask why the Institution should be more stringent upon a purely fire risk question than are any of the fire office rules. Surely the fire offices, with all their experience, have fixed a safe limit. Now what are the fire office rules on this subject. The Phœnix rules stipulate that any woodwork near a dynamo, motor, or resistance should be protected by fireproof material, but no distance is named. The Liverpool, London and Globe Insurance Company prefer that resistances should be on a brick or stone wall, isolated from inflammable material, no distance being stated. The London and Lancashire Fire Insurance Company, whilst giving the same distances as the Institution rules, recognise the absurdity and practical impossibility of the latter; they realise that in practice neither a dynamo nor a motor can be raised 4 feet above the floor (if the latter happen to be wood), except in rare cases, so the word "unprotected" is inserted, making the rule read common-sense. Thus: "Dynamo to be placed 4 feet vertically from any *unprotected* woodwork." But the obvious course is to protect it, so the next rule reads: "Dynamos to be placed on a sheet of metal of sufficient size to protect the floor when fixed on a non-fireproof floor." The same rule applies to *all* resistances, whether for motors or arc lamps. These, rules, whilst being based on those of the Institution, are amplified and made more definite.

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combustible material *other than their seating*, thus recognising what apparently the Institution forgot, viz., that a dynamo could not be fixed in mid-air, but must have a seating of some kind. The same rule applies to resistances. The Royal Insurance Company's rule on the subject is practically the same as that of the London and Lancashire Company, and these are the only rules the writer has seen which give diagrams of connections, and photographs of apparatus to illustrate and amplify the text.

It will be seen from the foregoing remarks how diverse and unpractical are the requirements both of the Institution and Supply rules, and how very wide of the mark they are in dealing with simple questions of fire risk. What could be more absurd than the rule that all motor resistances should be on brick or stone walls, except the suggestion that they should be placed "outside of the building." Imagine for a moment a large printing establishment, employing upwards of 100 motors, each provided with a starting switch, and separate regulating switch. It is necessary that the starting and controlling switches should be near the machines, and, assuming the switches to have on the average 10 steps, it would be necessary, if the resistances are placed on the walls, to run at least 2,000 connecting wires between the machines and the walls. Apart from the practical difficulties involved, the fire risk from 2,000 wires would have also to be considered. In Glasgow and Edinburgh only four wires are allowed on one tube, so that in addition to the tube carrying the supply wires, there would be at least 5 other tubes radiating from each machine to the sides of the building, or say about 600 tubes altogether.

Another rule, made only to be broken, is that which limits the temperature of the resistance coils of starting switches and arc lamps to 212 degrees Fahr., "even if left continuously in use." Now a starting resistance never is left continuously in use, unless it is designed to act also as a regulating resistance. Why, therefore, should it be designed to meet conditions that will never occur, or why should a consumer be forced to pay double the necessary price for a starting switch ? Starting switches are generally so designed that it is impossible to leave them in an intermediate position, that is to say, in a position in which a current could pass through the starting coils. And, it is

safe to say, that any of the regular patterns of starting resistances, of which there are many thousands in use, would burn out if the normal motor current were passed through for say 10 minutes, and most of them would burn out in less than three minutes. Not only are starting resistances not designed for continuously carrying the current, but the same applies to the contact plates of the switch, and it would be illogical to increase the current-carrying capacity of the one and not the other. What the rule amounts to, therefore, is, that all starting switches and resistances should be large enough to serve as speed regulators, which would practically double the cost, and be provided with abnormally large resistances even for speed regulators. Many people seem to lose sight of the fact that the function of a resistance coil is to dissipate energy in the form of heat, and that it would be, if not impossible, exceedingly inconvenient to provide space in most cases for the enormous coils that would be required if low temperatures are insisted upon. Why! the temperature of *unprotected* steam pipes and connections in Central Generating Stations is very considerably higher than is permissible for *protected* resistance coils in the same room by this rule.

In connection with motor work there are quite a number of rules that need standardising. First is the question of the maximum starting current permissible. It is apparent from the rules that the distributing mains in many towns are cut so fine that any current over 5 amperes suddenly switched on to one circuit is sufficient to disturb the pressure in neighbouring circuits. It does not seem quite fair to the motor user that he should have to pay for complicated and expensive apparatus for the sole purpose of enabling the suppliers to cut down capital outlay in cables for lighting purposes. If switching on or off the full motor current causes a disturbance in the neighbouring lighting circuits, surely it is the business of the supply authorities to lay down separate mains for power purposes. Many of them specify that separate circuits shall be run for motors and lighting *inside* the consumers' premises, a matter quite outside their province, yet, in addition to this, they impose vexatious restrictions on the motor user to enable themselves to use the same supply circuits for both motors and lighting. But to come back to the want of

uniformity in the requirements. These vary from a starting current not exceeding the normal full-load current on the City of London mains, down through various stages to a starting current not exceeding 5 amperes on the Glasgow and some other towns' mains. Nor are the rules always consistent even in the same district. On the Chelsea supply, a 3 H.P. motor may, on starting, exceed its full-load current of 25 per cent., say 16½ amperes. On the same supply, if a motor exceed 3 H.P., its starting current must not exceed 10 amperes, nor increase in steps exceeding 5 amperes each. On the Manchester Supply, no motor must take more than 10 amperes when first switched on, nor increase in steps exceeding 10 amperes. On the same circuit, a 10-ampere arc lamp may, on striking, take 18 amperes, and a 15-ampere arc 27 amperes, whilst an arc requiring normally more than 15 amperes must have a graduated starting resistance limiting the starting current to 15 amperes, and any additional current to 10-ampere steps. In Manchester, therefore, the extraordinary condition exists that a motor, no matter how large, must not take a starting current of more than, roughly, one-third of the current permitted to a 15-ampere arc lamp, and a 10-ampere lamp may take a larger starting current than a 20-ampere one. In Glasgow the starting current must not exceed 5 amperes nor increase in more than 5-ampere steps; in Carlisle and other towns using the same set of rules the starting current must not exceed 5 amperes, and the additional steps must not cause disturbance to the lighting circuits. Many rules permit 10 amperes starting current with the same subsequent conditions as the last named. A fair proportion of the rules call for a mechanical device or overload cut-off to prevent too rapid starting. Any ordinary overload device would fail to pass the Manchester test of pushing the starting switch suddenly over all the contacts to "full on," as the current will considerably exceed the limit before the inertia of the knock-off permits the switch to break circuit; nothing, therefore, but a slow motion gear will meet the case. But, when all the above conditions have been complied with, nothing can prevent the motor current, during normal working conditions, from continually varying through far wider ranges than 10 amperes. A motor driving a printing machine will not only suddenly fall from

full load to zero, but will at times actually fall beyond this and act as a dynamo and put current back into the mains, owing to the inertia of the machine connected with it. A motor driving a pair of cotton spinning mules will vary instantly from light load, say 10 amperes up to 200 amperes, and then quickly fall to 40 amperes, and then back to light load, and will repeat this cycle every few seconds. A motor driving a heavy planing machine may vary between 30 and 90 amperes every few seconds, yet in both the latter cases the starting up could comply even with the Glasgow conditions, as the motor would start on a loose pulley. Or, take the case of a newspaper printing machine absorbing 50 H.P. It must be possible to stop the machine instantly from any part of the machine, and it is not obvious why starting should be more detrimental to neighbouring lamps than stopping. To the uninitiated it would seem that the opposite is the case.

The Board of Trade rules are too well known to need repetition in full here. As has already been mentioned, on circuits of 250 volts and upwards all lines forming the connections to motors, or otherwise, must be completely enclosed in metallic casing as far as practicable, the casing being efficiently connected with earth. Each motor to have a switch under the control of the attendant by means of which all pressure can be cut off from the motor or from any apparatus in connection with it. Fuses on each pole to be provided. All switches and cut-outs to be so enclosed as to prevent danger from shock or fire. The above is a brief summary of the Board of Trade requirements, and it is interesting to observe how these apparently simple rules have been interpreted by different people. To take the enclosing and earthing first. Whilst in some localities it has been found that the ordinary steel tubing, known as "Simplex" or "Crown tubing," meets all the requirements for enclosing cables without any special bonding of joints, in others it is required that each joint should be bonded or that an earthed bare copper wire shall be enclosed throughout the full length of the tube, whilst in other places nothing but screwed gas-piping is passed. Then, as to the method of earthing. In Bristol all casings and frames, whether of motors, wires, switches, or resistances, must be earthed with a wire capable of carrying

ten times the fusing current of the main fuse. In Bury, Glasgow, etc., the earthing wire must be equal in section to the conductor ; in Carlisle, Grimsby, West Hartlepool, York, and other towns which have adopted the same set of rules, all motors are to be efficiently *insulated* from earth. This rule may refer to the windings of the motors and not to the frames, but nothing further is specified. In Edinburgh, the frames of all motors, whether 230 or 460 volts, must be earthed. In Manchester, all motors, whether on the 100, 200, or 400-volt circuits, are to be connected to earth with a copper conductor, equal in section to the motor conductor, but need not exceed 10 square millimetres. Resistances on 400-volt circuits to have metallic covers connected to earth. In Reading, the switches as well as the wire on 400-volt circuits are to be enclosed in earthed metallic sheathing. In Sunderland, the frames of 400-volt motors must be earthed by a cable not less than 7/18, quite regardless of the size of the motor. It would appear from the foregoing, that the almost general feeling among station engineers is that the Board of Trade rule as to enclosing and earthing applies to cables, switches, and resistance frames, as well as to motors, but, Glasgow again forms the notable exception, and insists on all resistance frames being *insulated* from earth.

The various other points in connection with motor work would occupy too much time to specify in detail. It might, however, be noted that some of the London companies specify that motors must be shunt wound. This is certainly not the best for a very variable load, even from the Supply Company's point of view ; whilst some specify that the shunt shall be broken on an inductive resistance, which is contrary to ordinary practice. The County of London, and Brush, are exceptional in asking for a single pole switch only, which is to be on the positive pole which forms the inner wire of the Company's mains. Possibly the reason for this is that the outer is earthed, and, if this be so, it is interesting to note, as the rules stipulate that all work must be carried out in accordance with the rules of the fire offices, that the Phœnix Office has a rule to this effect, "Switches and cut-outs should always act on the internal (or live) wire when the system is earthed," followed by the characteristic and amusing saving clause, "but switches and fuses may be

required on the other wire should the technical adviser to the fire office consider it advisable." The Supply Company further requires a switch and fuse on each main, near the point of supply, and, on the same subject, one of the Phœnix rules on page 15 reads, "when one main of a high-tension system is earthed, that main need *not* have a cut-out." Then, of course, the saving clause comes in, "unless required by the technical adviser of the fire office." On turning to page 28, another rule reads, "if one pole of a supply system be 'earthed,' each conductor *must* still have a switch and cut-out at its point of entrance into the consumers' premises," then, with really praiseworthy consistency, the usual exception, "unless permission to the contrary be given, etc."

Upon the question of earthing, Manchester has exceptional rules. Every radiator, including stoves, hot plates, ovens and cooking apparatus generally, must be earthed. In the case of portable apparatus this means a triple flexible conductor, and special 3 connection plugs and sockets. Electric kettles or other portable heaters must stand at least 6 inches above a table or anything combustible, and if electric irons and curling tongs come within the definition, electric laundry work is impossible in the Manchester district, and ladies must still depend upon the uncertain spirit lamp or gas jet to heat their tongs.

Without referring to the question of insulation resistance, upon which subject Mr. Pigg has dealt so exhaustively, the writer hopes he has said enough to awaken in the members some sense of the great need that exists for one definite and comprehensive set of rules, rules which shall be self-luminous, needing no interpreter, rules that the wayfaring man, though a jerry wireman, can understand and work to, and rules therefore that may be enforced.

Newcastle has ever been in the van in the March of Progress, and we of this section of the Institution must see to it that we worthily uphold the tradition. We must aim at being foremost among the local sections in everything that makes for the advancement either of the commercial or scientific interests of the industry with which we are all so proud, and justly proud, to be associated.

If, by our voice and influence, we can hasten the day when uniformity shall reign, even only in the matter of

wiring rules, we shall have done not a little to justify our existence.

Mr. Turnbull.

Mr. C. TURNBULL: The writer of the paper appears to think that standardisation may mean stagnation. I think, however, that there is little to fear from this, as standardisation really means that change is only made in the interests of progress instead of in a haphazard fashion. The business firms who standardise most are almost always the most progressive. I will first of all answer some of the criticisms on the Tynemouth rules. The writer of the paper objects to the rule that switches should be on the red wire. My reason for this is to ensure that switches shall be on the live wire of our three-wire system, so that if a switch be off, the fitting connected to it will be dead. The rule is convenient to remember—red wire danger wire; black wire neutral or dead wire. With regard to the writer's idea that the station has no right to object to a heavy drop of pressure in a consumer's premises, he here exposes himself to the suggestion that he is backing up the "jerry-wirer." Certainly the station has a great deal to do with the proper wiring of consumer's premises. I knew of one case, for instance, where a large shop was wired on the heavy-drop system, and the owner of this shop never ceased to write strong letters to the engineer of the station. He also created discontent amongst other consumers and prospective consumers, and I am not sure if eventually he did not put down his own plant. Furthermore, too little copper means heating and danger of fire. The consumer must be protected in the present state of matters, and the station engineer is the only one who can protect him. With regard to the insulating of switch handles, I have known cases where you could not switch on the light without getting a shock.

With the spirit of the paper, however, I am in entire sympathy. I think it would be a very excellent thing if we could have in house-wiring something akin to Lloyds' rules in shipping. Some three or four specifications could be drawn up to suit all classes of work, from cases where only the very highest quality was required, down to cases where work of the cheapest kind consistent with safety was aimed at. When a wiring firm contracted to wire a building, they could state on which specification they were tendering, so that every one would be on equality. Laws need administrators, and to carry out this idea properly it would be necessary to have a laboratory—preferably in charge of the Institution—which would examine and pass all suitable fittings, giving them a certificate that they could be used under a certain specification. I think that the expense might be easily met by contributions from the various stations, and also by fees from the manufacturers for testing fittings. Jerry-wiring firms wonld be put on the black list if necessary. All disputes could be referred to this department. By means such as this, I think that standardisation and progress could be assured.

Mr. Moir.

Mr. ALEX. MOIR: Before referring to a matter dealt with in the Fire Office rules, I would like to support Mr. Turnbull in his contention that the use of distinctive colours for positive and negative leads is a real advantage. Certainly, whatever may be the practice in electric

WIRING RULES.

Authority.	General.	Main Switches.	Cutouts.	Branch Circuits and Switches.	Wall Sockets, Ceiling Roses, Lampholders, etc.	Conductors.	Casing, etc.	Motors and Dynamos.	Arc Lamps, Cooking, Heating, etc.	Insulation Tests.
Phœnix Fire Office, 30th Edition, 1900.		House mains to have a switch on each pole coupled together; also fuse on each wire. This applies to any building where current is generated externally. Dynamos, batteries, and motors to have switch and cutout on both poles.	Length of break 1 inch for 100 volts. Length of break 1½ inch for 100–200 volts. Cutout on each pole if 200 volts and over, and on all principal branches. On 100-volt circuits, if 5 A. distributing circuits used with fuses on each pole, no further fuses needed. No fuses necessary on an earthed main, unless required by Fire Office. A fuse on middle wire of a 3-wire system may be larger than others. Each regulating cell of battery to have a cutout as near cells as possible.	3-ampere circuits recommended on 100 volts and 2½ amperes on 200-volt installations. Switches and cutouts on each pole of motors, heaters, ovens, and the like. Separate circuits for lighting, motors, and heating.	No fuses in ceiling roses on 200 volts and over. Ceiling roses to be fixed to back blocks. Key sockets not allowed without permission. Celluloid shades not allowed. Floor sockets ditto. Heating socket terminals to be automatically covered when plug is withdrawn. No portables or flexibles to be used in shop windows.	1,000 amperes per square inch up to 100 amperes. To be copper 98 per cent. conductivity; all above No. 16 s.w.g. stranded. Minimum size for lighting No. 18: for telephones No 20. (Copper not obligatory in all cases.) Permission to be obtained for concentrics. Insulation vulcanised indiarubber unless permission to contrary. 500 megohms per mile for dry places. 1,000 megohms per mile for damp places.	Iron or other approved tubes or wood casing. In hazardous risks wood casing must be treated with fireproof paint, and in cell rooms with acid proof compound. Conductors may be bunched in iron tubes but not in wood casings.	If placed in any work-room where a hazardous process is carried on, motors must be placed in a fire-proof compartment, ventilated only to the outside air and not into the building.* Resistances to be inside the above compartment. Metal cases not to be used to cover a motor if such cause undue heat or danger of shock. In some cases, above precautions unnecessary, so details should be submitted to Fire Office. All motors to be safe distance from unprotected woodwork. Motors to be well insulated from earth. Separate circuit to each motor and switch on each pole. Starting switch to have no voltage and preferably overload cutout. Resistances enclosed in metal case or box. Frames of motors over 200 volts to be earthed. V. A. and speed to be on name plate. * This rule together with the others issued by the Fire Offices Committee are printed in full in the London, Liverpool and Globe Rules.	Resistances to be in metal boxes. Naked arcs not allowed in doors. Arcs not to be used in drapers' shops without permission. (V. branch circuits.)	230 volts continuous and under Test at 100 volts between wires and also to earth 12½ megohms per light. Alternating 25 M. minimum: I.R. for a power installation up to 400 volts must not be less than one megohm.
London, Liverpool, and Globe Insurance. 1900 Edition.	This Company passes Installations when wired in accordance with these rules or those of the I.E.E., or those of the Supply Company. The Rules apply to Lighting Installations at a pressure not exceeding 250 volts. See "Special Risk" supplement for 500 v., also for Theatres and hazardous risks.	Requirements generally similar to Phœnix. Main switches preferably coupled together. Main fuse on supply side of main switch.	Length of break to be sufficient to prevent permanent arcing. + & – fuses should not be under same cover at any voltage and must not be if over 130 volts. Length of break if over 130 volts varies 1½ inches to 6 inches. For 500-volt motors magnetic blow-outs preferred. No cutouts in Accumulator Rooms.	D.P. Switch and cutout for heaters, cookers, etc., at junction of flexible conductors. 10-ampere circuits recommended up to 130-volts. 5 ampere circuits over 130 volts. Grouping of cutouts advised, particularly in mills, warehouses, and the like. In such places D.P. cutouts not allowed.	Terminals of sockets for heating, etc., appliances to be protected when not in use and to be marked with the current they are designed for. Lampholders not to be used as wall sockets. No fuses in ceiling roses or sockets over 150 volts. Ceiling roses, switches, and the like not to be fixed direct to walls or ceilings but on wood blocks. (See special supplement for hazardous risks.) In cotton stores incandescent lamps to be protected by thick outer globes. Switch lampholders not allowed in pattern stores.	For incandescent lighting:— 1,500 amperes per square inch up to 10 amperes. 1,000 amperes per square inch, 10 amperes up to 100 amperes. 800 amperes per square inch over 100 amperes. For arc lamps, motors, heating, etc.:— 1,000 amperes per square inch up to 50 amperes. 800 amperes per square inch over 50 amperes. Stranded below 18 and above 14 s.w.g. No 18 to be smallest area. Insulation other than vulcanised Indiarubber to be submitted for approval. Minimum insulation resistance 300 megohms per mile, for 500 volts insulation resistance, 1,000 megohms per mile. In salted produce stores, conductors to be lead covered and put in iron pipe. Special rules *re* bare conductors for cranes, etc.	Conduits, wood casing, insulators, metal clips, wood cleats, depending upon nature of building. Wood casing or cleats should be treated before erection with waterproof paint or varnish. In false roofs, beneath floorboards, where liable to become wetted, if wood casing used the + and – conductors should be in separate casings. In permanently damp places, wood casings not approved, unless lead-covered wires used. Casing in damp places to be blocked out at least ½ in. from walls or ceilings. Twin flexible may be used in fireproof tubing. For 500 volts. If conductors not armoured concentric must be in metal conduit equal to w.i. gas piping which must be earthed.	In working-rooms to be of enclosed type, wood covers over open type motors not approved. D.P. switch and cutout to each motor, also regulating switch so arranged that the D.P. switch only is used to cut current off. Regulating switch to have automatic release. Name plate on motor with V. A. and Revs. Terminals to be guarded, large unenclosed motors to be provided with a. w.p. cover for use in case of fire to prevent damage by water. An ammeter should be used on motor circuit installations.	Generally similar to Phœnix (v. branch circuits). Cooking and heating appliances to be raised 2 inches from table. Arc lamp resistances to be fireproof and wood-work in vicinity to be protected with asbestos. Resistance not to be in lamp case in wood-working stores, shops, etc.	Leakage at any time not to exceed $\frac{1}{10000}$th when tested at 200 volts or at double the working volts either between conductors or to earth.

Authority.	General.	Main Switch and Fuse.	Branch Switches, Fuses, and Circuits.	Ceiling Roses, Plug Connectors, and Lampholders.	Conductors.	Casing.	Dynamos, Motors, and Accessories.	Arc Lamps, Heating Apparatus, and Accessories.	Insulation Test.
Institution of Electrical Engineers, 1897.	Rules are such as may be strictly enforced to ensure freedom from fire risk, extinction, failure of supply, or danger to person, combined with economy of installation and maintenance.	Switchboards, front connections preferred.	5A. circuits recommended. Ideal system ; separate circuit to each lamp. Fuses to be so designed that a larger fuse than intended cannot be used. Fuses to be ventilated to avoid fracture ; the covers to catch and retain the fused metal.	C.R. need not have fuses if there is already in the circuit a fuse small enough to protect the flexible ; sockets—on a system with 5 A circuits and fuses on each pole, no need for fuses in sockets. If exceeding 5 A. on circuits up to 125 V., or 3 A. on circuits up to 250 V. sockets should have fuses.	Density, such as not to cause a rise in temperature of more than 30 degs. F. (Table of sizes given.) H.C. copper 100 degs. Conductivity standard :—" A copper wire weighing 100 grs. 100 ins. long = ·1516 ohm. at 60 deg. F." Insulation Resistance, rubber covered, 300 megohms to 1200 megohms, according to size (known as 300 megohm class). Lead-covered paper and fibrous cables to stand a test of 2,500 volt. alt. 40 to 100 for 10 minutes after bending as described ; flex cords to stand 1000 volt. alt. 40 to 100 periods applied between two conductors whilst within 3 feet of a pan of boiling water, and exposed to the vapour. Smallest section, No. 18 s.w.g. Standard above, No. 14 ,,	Draw-in system with incombustible tube preferred to casing. Bunching permitted in draw-in system.	Dynamos and motors, starting switches, etc., to be spaced 12 inches from woodwork, measured horizontally, and 4 feet vertically. Frames of dynamos and motors of 250 volts and over to be earthed. Coils of resistances not to heat more than 212 degs. F., even if left continuously in circuit. Coils enclosed in ventilated metal cases.	Netted globes : Arc resistances, same rule as motor resistances, but only half the distance from woodwork. Resistances. See motors for temperature.	To be tested with twice their ordinary E.M.F. after one minute's electrification : 10 megohms per ampere required. Second test 10 days.

Authority.	General.	Voltage of Supply.	Main Switch and Fuse.	Branch Switches, Fuses, and Circuits.	Ceiling Roses, Plug Connectors and Lampholders.	Conductors.	Casing.	Motors and Accessories.	Arc Lamps, Heating Apparatus, and Accessories.	Insulation Tests.
Blackpool Corporation. Issued January, 1897. Received 30th November, 1900.	Corporation have the right to require Contractor to open any joint, remove any casing wire or fittings, and re-instate at his own expense (whether defective or not). To be in accordance with rules of Fire Offices and I.E.E. Corporation take no responsibility.	200 volts.	One main fuse each pole to be fixed by contractor. Porcelain base 1½ inches break. One main switch on each pole fixed by contractor.	Slates not allowed unless soaked in boiled paraffin wax, stove enamelled, and all holes bushed with ebonite. No circuit switch to control more than 40·16 c.p. lamps, unless by written permission of engineer, and under such conditions as he may see fit to impose. Fuse break ¾ inch. Combined switch and fuse not allowed. D.P. switch or fuse not allowed.		1,000 amperes per sq. in. density. Copper 98 per cent. conductivity, Matthiesen's standard. No section below No. 18 s.w.g. Stranded above No. 16 s.w.g. 2,500 meghoms per mile if vulcanised indiarubber. If other than vulcanised indiarubber a high insulation resistance not recommended, but to be tested with 800 volts alternating for 1 hour.	Not recommended under any circumstances, and only allowed in face work. Buried wires to be lead-covered or in iron pipes, porcelain ducts or armoured bitumen tubing outside conductors, or in wet positions to be lead-covered, or in armoured bitumen tubing.	Resistances 18 inches clear of all woodwork or inflammable material. Preferably on brick walls or outside the buildings.	Resistances for arcs, same as for motors.	If vulcanised indiarubber covered cables not used, no insulation test, but tested for at least 15 minutes with 400 volts alternating. Insulation resis. to earth $\frac{20 \text{ megohms}}{\text{lamps.}}$ Arcs and motors each equal to 10 lamps. 10/6 for second tests. If I.R. of any installation fall below standard mentioned above, the Corporation may disconnect with or without notice, according to the seriousness of the defect.
Bristol Corporation. Motor Regulations only. Issued 1900.	The rules are additional to Corporation ordinary rules, and must be observed.	250 volts. up to 5 h.p. 500 volts. over 5 h.p.	D.P. main switch and fuse provided by consumer within one foot of meter, capable of breaking twice the maximum current required. If 2 or more 250 volt motors totalling over 10 B.H.P. on any installation, these to be balanced on three-wire system.			To be run in earthed pipe or tube. If pipe not screwed, an earth-wire capable of carrying 10 times fusing current of main fuse to be run inside the pipe.		Motors to be enclosed type, or enclosed in metal cases. All frames of motors, casings of switches, resistances, and cables to be earthed by a wire capable of carrying 10 times the fusing current of main fuse. Starting switches to limit current to 10-ampere steps; fuses or auto cutouts, also minimum cutoff. D.P. emergency switch. All terminals enclosed.		
Bury. (No date.) Received 30th November, 1900.	Connection free within 60 feet of mains. Installations must be in accordance with Corporation Rules, and Fire Office Rules.	220 volts. for lamps. ,, ,, small motors. 440 volts for 3 h.p. and over.	1 main fuse provided by contractor and one by Corporation. Main switch and fuse by contractor. If over 60·8 c.p., 2 required.	No branch switch to control more than 10·8 c.p. Fuses do., and 1½ inch break, preferably of copper strand.		Copper not literally specified. Smallest wire permitted, No. 18, except in fittings No. 20. Insul. resis., 600 megohms per mile. Vulcanised indiarubber insulation, unless engineer sanctions anything else. Density 1,000 amperes per sq. in.	Nothing specified in detail. Wires for 440 volts in screwed piping earthed.	Frames 440 volts earthed with a wire equal in section to conductors. Starting switch to have worm wheel or other slow motion device. (Same applies to all apparatus requiring a large current.)		I.R. (presumably to earth.) 10 lamps 10 megohms. 25 ,, 4 ,, 50 ,, 2 ,, 75 ,, 1·33 ,, 100 ,, 1·00 ,, 150 ,, ·67 ,, 200 ,, ·50 ,, 300 ,, ·53 ,, Arcs ,, 1 ,, Motor and accessories 1 ,, Disconnected if below 5,000 ohms.
Carlisle Corporation. Dated December, 1898. Received 31st December, 1900.	As West Hartlepool.	230 volts. 460 volts for motors over 4 h.p.	Main fuse supplied by Corporation and on no account by contractor, etc., etc., as at West Hartlepool.	As West Hartlepool.		As West Hartlepool.	As West Hartlepool, York, etc.	As West Hartlepool and York.		
Edinburgh. Dated June, 1900. Received November, 1900.	If more than 10 yards from service manhole the consumer to pay the extra length.	230 volts each side 3-wire system for lamps. 230 volt motors to 5 h.p. 460 ,, over 5 h.p.	Main fuse fixed by Corporation. Consumer to provide D.P. switch, but no fuses unless in tenements, where each consumer must have a fuse on each pole. Main fuses to be 3 inches long.	2 separate switchboards required on 3-wire system, *i.e.*, for lighting installation of over 25 A., 1 foot between. Fuses on sub-distributing boards 2½ inches long and 1½ inches apart. No switch should turn on more than 3 amperes. Sub-fuses should not control more than 6 lamps (if 8 c.p. this is less than 1 A.) 3 A. cutouts on both poles. S.P. fuses preferred to D.P., *i.e.*, one S.P., fuse on each wire. Fuse wire to be *tin*.	No fuses in C.R. or wall sockets. Wall sockets for heating and cooking apparatus to be of a special character.	Density not stated. Insulation of conductors, dry places, 500 megohms per mile. Damp places, 600 megohms per mile. In plaster work and walls, 1,000 megohms per mile. Through damp vaults or out in the open, 2,000 megohms per mile. L. c. wires not recommended.	In damp vaults or in open, water-proofed casing or iron pipes. Metal pipes in concealed places. All pipes connected to earth (not by a gas pipe). 4 wires can be run in 1 pipe, not more. For motors or heating apparatus, wires in iron or brass pipe.	Frames to be connected to earth. For insulation test a motor shall be rated at its equivalent in lamps. Pilot lamp for motors controlled from a distance. Motors requiring over 5 A. starting current to have a starting resistance with mechanical slow motion. To cause no disturbance in its own or neighbouring circuits on starting. D.P. switch and fuse 6 inches long in iron case. Resistances for motors (or arcs) not to be fixed on or near woodwork. Should be on brick or stone walls, 6 inches from wall, resistance protected by perforated metal cover.	Arc lamps of large size (current not given), to have resistance to reduce rate at which current is thrown on or off (nothing specified about lamp blowing out.) Heating apparatus sockets to be special character.	Fee for second test, 10s. 6d. Testing press, 500 volts. 12 lamps 5 megohms = 60 mghms. p. lp. 25 ,, 2·5 ,, = 62½ ,, 50 ,, 1·5 ,, = 75 ,, 75 ,, 1·25 ,, = 87½ ,, 100 ,, 1 ,, = 100 ,, 150 ,, ·75 ,, = 112 ,, 200 ,, ·5 ,, = 100 ,, 250 ,, ·3 ,, = 75 ,, 300 ,, ·2 ,, = 60 ,, (Above is presumably I.R. to earth.) Between wires must in no case be less than 75,000 ohms. If I.R. fall below 10,000 installation may be cut off.

Authority.	General.	Voltage of Supply.	Main Switch and Fuse.	Branch Switches, Fuses, and Circuits.	Ceiling Roses, Plug Connectors, and Lampholders.	Conductors.	Casing.	Motors and Accessories.	Arc Lamps, Heating Apparatus, and Accessories.	Insulation Tests.
Glasgow Corporation. Dated September, 1900. Received November, 1900.	Terms and conditions of supply, for protection of Corporation, of consumers individually, collectively, Corporation take no responsibility. All work must be carried out in accordance with general rules issued by Corporation. Rules not to be taken as a text book for the instruction of wiremen. Rules of Inst. E.E. embodied and amplified. Engineer may condemn work he considers defective. Connection free if not exceeding 60 feet.	250 volts for lighting up to 25 amperes. 500 volts for lighting 3-wire system over 25 amperes. 250 volts for motors up to 5 H.P. 500 volts for motors over 5 H.P.	Main fuse supplied by Corporation in position determined by Engineer. In motor installations a separate D.P. switch and fuse within 3 feet of Corporation fuse. 2 circuits if over 25 amperes + & − on separate bases connected together by a link and insulating fillet up to link or cover. No conductor to carry more than 100 amps. If 2 required, 1 ft. clear space between them. Break of Switches :— Amps. 200 volts. 500 volts. 5 ½ in. 1 in. 10 1 in. 2 in. 25 1½ in. 3 in. 50 2 in. 4 in. 100 2½ in. 5 in. 250 3 in. 6 in. Fuses : 5 1½ in. 2 in. 10 2 in. 2½ in. 25 2½ in. 3 in. 50 3 in. 3½ in. 100 3½ in. 4 in. 250 4 in. 4½ in.	Switchboards, all connections on front. No switch to control more than 10 amperes, and any apparatus requiring more than this to have a graduated switch. Separate fuse to each wire. 3 ampere circuits preferred, and must be used where possible. Fuses ventilated, etc., per I.E.E. Tin fuse ; preferably copper ends.	No fuses in C.R. ; if 3-ampere circuits ventilated covers. No fuses necessary in plug connectors, if 3-ampere circuits used. To be tested at 500 volts ; also at 50 per cent. extra current.	Outside in gardens, etc. If vulcanised indiarubber covered, 2,500 megohms per mile in earthenware or iron pipe 12 inches underground. Preferably lead cover in troughing, run in with bitumen, and covered with bricks or tiles. Interior : Copper 100 per cent. conductivity. Same standard as I.E.E. All conductors stranded, etc., not more than 100 amperes on any single conductor. Minimum size 3/22 : 1000 amperes per square inch up to 100 amperes. Insulation may be I.R., or paper, jute, etc. Insulation resistance to be 2,400 megohms per mile. Concentrics to have twice that resistance between conductors, or between outer and earth. Flexibles : Test same as I.E.E.	Draw-in system preferred to casing. No more than two wires of opposite polarity in any one tube. No elbows. Not more than four wires of same polarity in any one tube. All wires in wood casing separate. Tubes in walls to be filled in with sand or equal. Motor wires in iron pipe, and on separate circuits to lighting.	Motors over ¼ H.P. to have starter with no volt release, and overload release to act if switch put on too quickly ; *i.e.* as quickly as to disturb pressure of supply. 5-ampere starting current, 5-ampere steps, slow gear. No wood 12 inches from motor horizontally or 4 feet vertically above. Over 250 volt motors to be earthed with copper equal in size to conductor. Resistance frames to be insulated from earth.	Resistances, same rule as I.E.E.	Test at 500 volts after one min. electrification (to earth). 50 megohms per ordinary inc. lamp, or 10 megohms per ampere.
Grimsby Corporation. Dated September, 1899. Received November, 1900.	As West Hartlepool. Connection free if not exceeding 40 ft.	As West Hartlepool.	As West Hartlepool.	As West Hartlepool.	As West Hartlepool.	As West Hartlepool.	As West Hartlepool.	As West Hartlepool.	As West Hartlepool.	As West Hartlepool.
Hull Corporation. Dated July, 1896. Received November, 1900.	Instructions for guidance of consumers, embodying principal requirements necessary to ensure safety. Corporation accept no responsibility. If required, consumer to enter into written contract to take energy for two years to a value of 20 per cent. per annum on the undertaker's outlay.		Main fuse provided by Corporation. Main switch to be fixed by Contractor on each pole near Corporation fuse.	Circuits of 20 × 16 c.p. lamps, or 10-ampere arc lamp circuits. Combined switch and fuse prohibited.	Ceiling roses to have fuses. Wall sockets to have fuses.	To be insulated, preferably vulcanised indiarubber ; 600 megohms minimum. All conductors less than 18 or larger than 16 to be stranded. Density 1,000 amperes per square inch.	Grooved wood or other casing. Each conductor in separate groove or tube. Casing on damp walls to have 3 coats of paint before fixing.	Motors to be insulated from earth. An approved reg. resistance for starting motors to be provided.		At 200 volts. Insulation resistance must equal 40 megohms per ampere to earth. Between wires not to be less than 75,000 ohms.
Liverpool. Dated November, 1900. Received November, 1900.	Insulation to conform to Corporation Rules and to Fire Office Rules. Service lines run free 25 yards from distg. mains. B.O.T. Rules given for 460 volt motors. Motors over 12 H.P. on 460 volt.	230 volts and 460 volts.	No main circuit or meter to carry more than 100 amperes.	Cutouts not required on branches from a 7/22 cable, but cutouts to be put on both poles of a branch circuit, taken from a larger conductor than 7/22. Switch to be placed on every circuit greater than 7/22. Branch circuits not more than 12 amperes. All fuses to have at least 1½ ins. clear fuse wire between terminals. All switches, cutouts, and holders to have terminals of such a size that the full section of conductor can be seen from front.	No fuses to be placed in any switch, ceiling rose, or socket, in which both poles are under one cover. Wall sockets to be controlled by separate switch. No switch lampholders to be used on portable fittings, or on any circuit of greater area than 7/22. High voltage cutouts to have 4 in. break, and ventilated metal covers.	Tinned copper : minimum insulation resistance 600 megohms per mile. Smallest size No. 18. Stranded over No. 16. Damp places, lead-covered wire to be used. Circuits of over 230 volts minimum insulation resistance 1,000 megohms. On circuits over 230 volts conductors to be in iron tubes, earthed or in separate wood casings 10 inches apart. Density 1,000 amperes per square inch, 2 volts drop to furthest lamp.	Casing to be painted, or fireproof tubing used. In cellars, casing to be blocked out half an inch from wall. Casing may be fixed to walls by steel nails of oval section.	To have fireproof case, unless situated in separate fireproof portion of building. Starting switch to limit starting current to 10 amperes. Automatic overload, and no volt cutoff. Resistances not to be within six inches of woodwork, preferably on bare walls.	Arc lamp mains to have switch on each pole. Cooking and heating apparatus to have switch and fuse on each pole, and must be marked with pressure and current required. Resistances : (same rule as for motors.)	Fee for 2nd test 5s. Corporation have right to cut off supply if insulation resistance fall below "limit of safety." Motors : Insulation resistance between frame and winding = 20 megohms per amp. Complete installation between mains, also from mains to earth 20 megohms per ampere. Test pressure 200 volts.

Authority.	General.	Voltage of Supply.	Main Switch and Fuse.	Branch Switches, Fuses and Circuits.	Ceiling Roses, Plug Connectors, and Lampholders.	Conductors.	Casing.	Motors and Accessories.	Arc Lamps, Heating Apparatus, and Accessories.	Insulation Tests.
Manchester. Dated October, 1899. Received November, 1900.	Regulations to be observed by consumers and contractors will be enforced strictly. They are additional to and not in substitution of the ordinary wiring rules and Inst. of Electrical Engineer rules, to ensure safe and satisfactory supply. Corporation takes no responsibility. Will refuse to connect up any installation not in accordance with regulations. Articles, every description, to be approved by Corporation and certified. Yearly certificates given for samples approved. Samples in duplicate to be submitted, which become absolute property of Manchester Corporation. No application for a less period than 1 year will be accepted.	Lamps up to $2\frac{1}{2}$ kilowatts, 100 volts—1 pr. terminals. Lamps $2\frac{1}{2}$ to 5 kilowatts, 200 volts—2 pr. terminals. Lamps 5 kilowatts and above 400 volts—4 pr. terminals. Motors— Below $\frac{3}{4}$ kilowatts, 100 volts. Below $2\frac{1}{2}$ kilowatts, 200 volts. Above $2\frac{1}{2}$ kilowatts, 400 volts.	Main fuse supplied by Corporation. Contractor also to fix D.P. switch and fuse within 3 feet of meter. Not required in addition to motor D.P. switch in case of single motor if motor is within 15 feet from point of supply. + and – switch connected by insulated link.	Over 100 volts separate S.P. fuse each pole. $2\frac{1}{2}$-ampere circuits on 200 volts recommended. 5-ampere circuits on 100 volts. No fuses required beyond distributing boards.	Not to contain fuses on 200 volts circuit. Separate ceiling roses for each flexible. Separate switch for plug connections if more than 1 ampere: To have terminal for earth wire if for heating appliances.	Interior: Tinned copper: Vulcanised indiarubber 600 megohms. Exterior: Tinned copper: Vulcanised indiarubber, 2,500 megohms, or lead covered, bitumen paper, etc., 250 megohms preferably armed, laid in trough and filled in with bitumen. Flexibles: Vulcanised indiarubber or pure rubber of ·02 inch thick. Stranded all above No. 16. Minimum No. 18, nothing smaller to be used. Concentric conductors must be insulated from earth—same I.R.	Incombustible tubes, steel armour, or hard wood casing. Insulators allowed in fireproof buildings if out of reach. In damp walls (lead-covered) casing blocked out $\frac{3}{4}$ inch. Capping must only be screwed on outer edge. All conductors separate if in wood casing.	10 amperes at start and 10 ampere steps, gradual starting necessary either by gear or overload device. Interlocked D.P. switch. 2 S.P. fuses. Magnetic blow-out for 400 volts. Overload cutout necessary. Frame to be connected to earth with wire, equal in section to conductor, but need not exceed 10 square mm. Covers of resistances to be earthed on 400-volt circuits.	Arc lamps, starting current not to exceed 80 per cent. excess, *i.e.*, 15 amp. arc must not exceed 27 amperes. Larger than 15 amperes not to exceed 15 amperes at starting, nor more than 10 amperes each additional step, and cutout at same rate. Radiators, etc., to be earthed—fuse and switch each pole. Triple flexible sockets, 1 for earthing 20 inches clear of wood, etc. 6 inches clear above wood or inflammable material.	50 megohms per lamp of any c.p. up to 50. Arcs 5 megohms per lamp (15 amperes). Motors, 1 megohm frame to earth. Supply cut-off if $\frac{1}{10000}$ leakage (B.O.T. Rule). (Above test presumably to earth).
Newcastle-on-Tyne Electric Supply Company. Not dated. Received November, 1900.	Connection free 60 feet from main. Deposit of 4/- per 8 c.p. lamp or give security. Installations must comply with Company's Rules.	240 volts for lights. 240 volts for motors under 3 H.P. 480 volts for motors over 3 H.P.	Main fuse to be fixed by Company and one by contractor; latter to be set for lower current than former. 2 S.P. main switches and fuses, main fuses 2 inch break. If more than an equivalent of 100·32 watt-lamps, to have 2 circuits, one each side, and must be balanced, that is, long against long and short against short hour lamps. Arcs on separate circuit to incandescents.	No switch to turn off more than 75·32 watt-lamps on the 240-volt circuit. No sub-circuit more than fourteen 16-c.p. lamps, cutout on each pole. Arcs and incandescents to be on separate circuits.		Nil.	Nil.	Motor fuses to be either magnetic blow-out, or have 4-inch break. Company will undertake supervision of running of all motors after having first run to their satisfaction.	Nil.	Power to disconnect if below required standard. Insulation resistance 20 megohms per point. 1 arc or one motor = 10 points. Second test 10s. 6d. Test; both to earth and between conductors.
Reading Electric Supply Co. Dated July, 1900. Received November, 1900.	Connections free within 60 feet of distributing main. May require a deposit or security. Installations must comply with Company's Rules, in addition to those of Fire Office and Institute of Electrical Engineers. Company accept no responsibility.	100 or 200 volts alternating; or 200 volts c.c.; or 400 volts for motors over 4 H.P.	1 main fuse on each pole to be fixed by contractor; $1\frac{1}{2}$ inch minimum break; to break at less than Company's main fuse. 2 S.P. switches with contacts 3 inches apart, $1\frac{1}{2}$ inch break fixed on consumers' side of fuse.	Separate circuits from Company's terminals for 5 kilowatts and over, *i.e.*, each circuit to take less than 5 kilowatts.* D.P. fuses not allowed: $\frac{3}{4}$-inch minimum break for fuses. Combined switch and fuse not allowed. * This probably refers to lighting circuits only, otherwise it limits motors to 6 H.P.	Fuses in wall sockets or ceiling roses not allowed.	H.C. copper 100 per cent. conductivity by Matthiesen's standard. Not less than No. 18. Stranded above No. 16. Not more than $1\frac{1}{2}$ volts drop from Company's terminals to furthest lamp.	Buried conductors to be in insulating pipes or a special form of cable used. Metal tubes for single cable on alternating circuit not allowed. For 400 volts wiring, metal tubes earthed.	Flywheels on motors for intermittent work 10 h.p. and upwards. Submit details for special motor installations. Automatic release switch for motors over $\frac{1}{2}$ H.P. The words "start slowly" to be put on small motor starters. Over 4 H.P. a slow motion to be fitted making it impossible to switch on suddenly. 2 linked S.P. switches. All switches, wiring, etc., to be enclosed in metal casing earthed.	Resistances to be 18 inches from all wood or inflammable material.	Insulation resistance to earth. Tested at working pressure, 60 megohms per 8 c.p. lamp. 1st test free. 2nd test free. 3rd test 2s. 6d. 4th test 5s. Additional tests 5s. Current may be cut off if below standard.

Mr.
Turnbul

Mr. Moir.

Authority.	General.	Voltage of Supply.	Main Switch and Fuse.	Branch Circuit, Switch, and Fuse.	Ceiling Roses, Plug Connections and Lampholder.	Conductors.	Casing.	Motors and Accessories.	Arc Lamps, Heating Apparatus, and Accessories.	Insulation Test.
Salford. Dated May, 1900. Received November, 1900.	Work to be in accordance with these rules, and also with those of Fire Insurance Company and Institution of Electrical Engineers. Corporation have the right to require any joint to be opened up, or casing, fittings, or wires removed for inspection and to be replaced at the contractors' expense. Corporation accept no responsibility.	220 volts c.c. 440 volts c.c. 200 volts alternating.	Contractor to fix S.P. fuse in each main ; at least 4 inches apart, between consumer's main switch and house circuit, $1\frac{1}{2}$ inches clear break and set to fuse at a lower current than Borough Fuse. If over 25 amperes, 2 separate circuits to be run to supply terminals. 1 inch clear break for main or arc lamp switches.	Separate S.P. fuse on each wire + and-fuseboards to be kept 4 inches apart. Not more than ten 16-c.p. lamps controlled by 1 switch. D.P. fuses not allowed. Minimum break $\frac{3}{8}$ inch and same between any metal and terminals.	Incandescent lamps to be fixed in vertical position unless filaments specially supported.	Tinned copper 98 per cent., Matthiesen's standard, 1,000 amperes per square inch. Minimum size No 18. Stranded over 16. Insulation resis. 2,500 megohms not necessarily rubber-covered. No naked wires allowed.	Casing and iron piping or porcelain under plaster. In wet positions, porcelain ducts or wood-casing blocked out $\frac{3}{8}$ inch from wall, and cables lead-covered. Outside buildings on insulators 8 inches or 10 inches apart.	All motors over 1 h.p. to be 440 volts. Starting resistance to be such that no disturbance shall be caused in neighbouring lights in starting or stopping. Motors driving lifts, cranes, or circular saws to be provided with flywheel. Full details to be submitted before commencing any motor work.	Resistances to be 18 inches from wood or inflammable material, fixed preferably on a brick wall or outside buildings. Arc lamp switches to have 1 inch clear break	Between wire and earth 10 megohms per ampere. Installations liable to be disconnected if below standard. Second test 5s.
Sunderland. Dated September, 1899. Received November, 1900.	Rules to be observed by contractors and consumers to ensure safety and efficiency. Corporation accept no reponsibility. Power to make contractor open up joints and casing, and reinstate at his own expense.	220 and 440 volts. Motors specified to be wound for 220 volts, but 440-volt motors referred to also, but size not stated. Installation for over 100 8-c.p. lamps to be balanced on two circuits.	A main fuse supplied by Corporation. Contractor also to provide switch and fuse on each pole.	Fuse each pole (D.P. fuse not allowed). 10 lamp circuits. Switch with fuse not allowed.	Switch-holders not allowed. Separate switch and separate fuse to each plug connection. Ceiling roses not to have fuses in them, but must have a separate fuse.	Exterior wiring 2,000 megohms in W.P. casing ; lead-covered or iron pipes. Tinned copper 1,000 amperes per square inch not to be exceeded. 2-volt drop from meter to furthest lamp. Stranded above No 16. Minimum size No 18 for a single conductor. Insulation resistance, interior = 1,000 megohms per mile. On 440 volts circuit insulation resistance = 2,500 megohms per mile.	Preferably American whitewood, 2 coats shellac varnish before use. If out of sight, wood casing, earthenware casing, cement troughing, or insulated tubes or ducts. 440-volt conductivity in strong metal casing, earthed.	Motors for variable loads, as circular saws, etc., to have fly wheels (except lifts). Gradual starting necessary. 2 S.P. switches. 2 " fuses. 1 automatic cutout. Frame of 440 volt motors, connected to earth with wire not less than 7–18ths. Resistances to be enclosed in incombustible material.	Resistances in ventilated casing to be kept 12 inches clear of woodwork or inflammable material.	Motors 1 megohm frame to earth. Minimum between wire 75,000 ohms. 30 to 50 megohms per lamp to earth.
Tynemouth. January, 1900. Received Nov., 1900.	Supply lines laid free within 60 ft. of mains. Engineer may refuse supply if there is anything he considers unsatisfactory. Installation must be in accordance with Corporation Rules and Rules of Fire Insurance Company. Corporation accept no responsibility.	220 volts for lamps. 220 volts for motors } as 440 " " } directed.	Double or treble pole switches and fuses to be provided by consumer. Corporation also provides a main circuit. If over 25 amperes, 2 main circuits required.	No branch switch to turn on more than 5 amperes or 10 lamps. Branch cutouts on both wires. Fuse wires preferably copper. Minimum break $1\frac{1}{2}$ inches. All switches on red wire. Tumbler switch must be *on* when handle is *downwards*. Switch-holders forbidden.	To be H.V. type.	+ to be red. − to be black. Not more 2-volt drop furthest lamp. Maximum density 1,000 A. square inch. Minimum size No. 18. 98 per cent. conductivity. 600 megohms insulation resistance. If insulation not V.I.R., must be approved by Engineer. All flexible to be vulcanised.	May be wood, or other suitable conduit or pipe.	Starters to be approved by Engineer.	Any apparatus requiring large current, to have starting resistance.	Test Press, 220 volts. 12 lamps not less than 5 megohms. 25 " 2·5 " 50 " 1·5 " 75 " 1·25 " 100 " 1·52 " 150 " ·75 " 200 " ·5 " 300 " ·2 " Motors and heating apparatus to be reckoned in their equivalent of lamps of ·5 amperes each. If insulation resistance fall below 5000 ohms. installation will be disconnected. Second test, 2s. 6d.
Walker and Wallsend Union Gas Company.	Same as Newcastle throughout.									
West Hartlepool. In use 1901.	Rules issued for guidance of contractors and consumers. Corporation accept no responsibility. Installations to be also in accordance with Rules of Fire Offices and Inst. of Electrical Engineers.	230 volts for lighting and small motors. 460 volts for motors over 4 H.P.	Main fuse supplied by Corporation, and on no account by contractor. 2 S.P. switches to be fixed by contractor, protected by non-conducting cover, 3 in. between + & −, if under same cover. $\frac{3}{4}$ in. break for 40 8-c.p. 1 in. " over "	No switch for more than ten 8-c.p. except main. $\frac{1}{2}$ in. clear break. D.P. fuse not allowed. No fuse to carry more than ten 8-c.p. Non-Metallic covers and cases.	Switch lampholders, etc., generally to comply with Inst. Electrical Engineers' Rules.	H.C. 100 per cent. copper. Nothing smaller than No. 18. All stranded above No. 16. Insulation of V.I.R. or other approved material, 600 megohms ordinary places. 1,000 megohms damp, or in walls. 1,000 A. square inch density.	Hardwood casing or incombustible tube. In damp walls, casing to be blocked out $\frac{3}{4}$ inch, or pipes used. If casing embedded in plaster, to have two coats shellac varnish.	To be insulated from earth. For insulation resistance test. a motor will be rated as the number of lamps taking same energy. Starting current not to exceed 5 amperes. Resistance so proportioned as not to cause visible disturbances to any lights on its own or neighbouring circuit.	Arcs, where used intermittently, to have a starting resistance to reduce rate at which current is put on (nothing about switching off).	4 days' notice required. 10s. 6d. for second test. Test between wires at 230 volts. Insulation resistance = 230 megohms per lamp. 75,000 volts minimum. Board of Trade rule given as to cutting off supply.
York. February, 1899	As above.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.

AUTHORITY.	GENERAL.	VOLTAGE OF SUPPLY.	MAIN SWITCH AND FUSE.	BRANCH CIRCUIT SWITCH AND FUSE.	CEILING ROSES, PLUG CONNECTIGNS AND LAMPHOLDERS.	CONDUCTORS.	CASING.	MOTORS AND ACCESSORIES.	ARC LAMPS, HEATING APPARATUS, AND ACCESSORIES.	INSULATION TEST.
Chelsea Electricity Supply Co. Dated 1900 Received November, 1900.	The rules are to be observed by Contractors wiring houses, supplied from Company's mains. Fire Office rules also to be observed. Form of application for current to be signed by householder and witnessed. If signed by lady, she should state whether widow or spinster. Signature of a married lady not accepted unless accompanied by declaration that she has a separate estate.	200 v. for lamps or motors.	Contractor to fix 2 single-pole switches, but is forbidden to fix a main cutout. $\frac{1}{2}$ inch clear break for switches carrying up to 40·8 c.p. lamps, 1 inch above this. Metallic covers not allowed. No main circuit to carry more than 25 amperes. Company will fix a separate meter and cutout for each 25 amperes circuit. (N.B.—If this refers to motors, the largest motors permitted is 6 H.P.)	Each branch circuit to have 2 S.P. fuses, not to control more than 15 8-c.p. lamps = about $2\frac{1}{2}$ amperes. S.P. fuses $1\frac{1}{4}$ inch break, and on distributing boards to be $1\frac{1}{2}$ inch apart; to have fuse chamber, or otherwise be approved by Engineer. No D.P. fuses allowed. Fuse to consist of single wire not larger than No. 26 s.w.g. = 50 per cent. over $2\frac{1}{2}$ A. Copper fuses not permitted. Combined switch and fuse prohibited.	No fuse terminals allowed in sockets or ceiling roses. Celluloid lamp shades not allowed.	Nothing specified about insulation except that flexibles must be D.R. Nothing smaller than No. 18, not even flexibles. Current density :— 1,000 A. per square inch, not more than I.V. drop between the Company's cutout and any lamp.		Starting current for motors up to 3 H.P. not to exceed 25 per cent. above nominal current, *i.e.*, maximum starting current allowed (= about $16\frac{1}{2}$ A.) Motors over 3 H.P. starting current not to exceed 10 A., and increase in 5 A. steps. Magnet circuit in two halves in parallel which can be put in series when volts. increased to 400. Motor switches for 200 volts. not to have less than 1 inch clear break.		I.R. of motors up to 3 H.P. including its wiring and switch gear with frame to earth not less than that of an equivalent number of lamps. I.R. of larger motors $\frac{1}{2}$ megohm each. (Up to 60 W). 10 lamps 5·4 megohms per lamp. 20 ,, 3·2 ,, ,, 30 ,, 2·3 ,, ,, 40 ,, 1·8 ,, ,, 50 ,, 1·5 ,, ,, 75 ,, 1·0 ,, ,, 100 ,, 0·8 ,, ,, 150 ,, 0·5 ,, ,, This varies from 54 to 80 megohms per lamp. Rules do not state if to earth or between wires. 10s. 6d. fee for second test. Company reserve right to cut off supply if installation defective.
City of London Electric Lighting Company. Dated February, 1899. In use January, 1901.	Free service mains within 60 ft. of a public thoroughfare. Installations to conform to rules of Fire Office, Board of Trade, and these rules.	200 volts c.c. 400 volts c.c. 200 volts c.c.	Main fuse fixed by Company; D.P. switch by Contractor. If more than 50 amperes required, 2 separate circuits and meters.	Magnetic cutouts forbidden, unless approved by Engineer.	All ceiling roses, lampholders, etc., to be suitable for 200 volts. Switchholder not allowed. Fuses in C.R. not allowed.	V.I.R. (200 volts) or equally good material. 1,000 A. per square inch. Volts. loss not to exceed 2 volts. to furthest lamp. Minimum conductor = No. 18. Stranded over No. 14. Flexibles may equal ,, 20. 400 volts. minimum size ,, 16. I.R. 2,500 megohms per mile.	Wood casing not recommended. If used in damp places to be varnished or painted with waterproof composition inside and out. 400 volts. conductors in iron pipes.	Send details for approval for 400 volts. Starting current not to exceed normal working current. Automatic no volt. release on starter. Motors to be shunt wound. Field circuit to be made first and broken on an *inductive resistance or carbon break.	Send details for approval.	75 megohms per point tested at 200 volts. pressure to earth. Between wires must equal one megohm. 10s. 6d. for any test if I.R. found below Company's standard. 400 volt. motors, including wiring and fittings, etc., not less than 5 megohms for each motor. I.R. of motor itself one megohm.
County of London and Brush P.E.L. Company. Dated August, 1897. In use January, 1901.	Supply lines free within 60 ft. of mains.	100 volts. 200 volts (Wandsworth). 100 volts (alternating).	D.P. switch by consumer. ,, fuse by Company.	Magnetic cut-out not allowed.	S.P. fuse to protect all flexibles. Key sockets or switch holders forbidden except by special permit.	98 per cent. copper. 1,000 A. sq. inch, not more than 2 volts. drop to furthest lamp. Minimum section No. 18 switches. Stranded conductors above No. 16. Insulation to be V.I.R., or equally good material. 600 megohms per mile for ordinary work 1,000 ,, ,, for damp places. (Wandsworth) concentrics by permission.	Hardwood, in damp places to be varnished twice.	See below.	Where arc lamps used Engineer to be consulted, and the type of choking coil submitted. (W) above applies to motors.	Test at full working pressure, I.R. not less than 75 megohms per 8-c.p. lamp. Second test 10s. 6d.
County of London and Brush P.E.L. Company. Dated August, 1897. In use January, 1901. (Motor Rules.)	Work to be done in accordance with Rules of Fire Office, I.E.E., and Board of Trade.	500 volts. 2-wire continuous current.	D.P. switch and fuse provided by consumer.	Fuses to be on porcelain or vitrite bases. Length sufficient to prevent arcing. Switches must be S.P. only, and on the + pole.		As above. Minimum section No. 16 s.w.g. 2,500 megohms per mile I.R. Concentrics may be used with insulated outer.	Wires to be in iron pipes, earthed.	To be shunt wound, frame earthed. Field to be made before the armature and broken on an *inductive resistance or carbon break. Starter connected to + pole, and to have no volt. release.		I.R. of each motor with its wiring and accessories to be not less than 20 megohms.
Metropolitan E.S. Company. January, 1899. Received Nov., 1900.	Rules to be observed by wiring Contractors. Fire Office rules also to be observed.	100 volts c.c. 200 volts c.c. ? 100 volts alternating.	If more than 50 amperes required, 2 distinct circuits. Main D.P. switch to have at least $\frac{1}{2}$ inch break. To have a non-conducting cover On low tension supply, Contractor must not fix a D.P. main fuse, but a D.P. switch only. On the H.T. supply, Contractor to fix a D.P. main fuse, but not a switch.	Branch circuits of not more than 15 8-c.p., and to have fuse on each pole. Each branch circuit to have fuse on each lead, fixed on distributing boards $2\frac{1}{2}$ inches between opposite poles. Combination switch and fuse not allowed. $1\frac{1}{2}$ inch break : $2\frac{1}{2}$ inch between poles.	Ceiling roses and sockets not to have fuse terminals.	Tinned copper. 1,000 A. per square inch. Volts. drop not to exceed 1 per cent. to furthest lamp.		Motors and starters all over $\frac{1}{4}$ H.P. to be on 200 volts. Starting current not to exceed 25 per cent. of maximum working current.	Nothing special.	Minimum test up to 100 points one megohm. Second test 10s. 6d.

* Probably an error and "non-inductive" meant.

lighting, the man who attempted to equip or maintain a large telephone exchange without taking advantage of the different colourings of the various wires would find himself very much at sea. Mr. Moir.

The advent of the trolley wire and other overhead lighting and power circuits has brought about a new fire risk in the premises of users of open telephone lines. It has been proved that contact between power-circuits and unprotected telephone lines sometimes results in fire. The Fire Offices, therefore, have introduced rules for telephone users, and with that no one can quarrel. A telephone has to protected against disruptive discharge from an excessive E.M.F., and against dangerous heating from an excessive current. The Liverpool, London, and Globe Company very fairly insist upon an efficient lightning arrester and a fusible cut-out to act at one ampere. The Phœnix Office stipulates for a lightning arrester, a cut-out to act at one-third of an ampere, and an automatic earthing device to act when the normal pressure in the telephone line is exceeded by 50 per cent. Now, passing by the difficulty of finding a fuse that will give way at one-third of an ampere, I suggest that the stipulation regarding the automatic pressure device is ridiculous. In many a telephone line the pressure does not exceed six volts, so that to conform to this rule a nine-volt pressure would be required to give a disruptive discharge across an air-gap. Even where hand magnetos are used the pressure generated does not exceed 60 volts, and, of course, with 90 volts no pressure device would act. Indeed, it requires an extremely sensitive arrangement to get a spark across the air space of a carbon-mica protector at 300 volts. The Phœnix Office would do well to recast its telephone rules, and simply insist upon an efficient lightning arrester, and, in addition, a one-ampere fuse, or a half-ampere heat-coil.

Mr. A. E. Gott: The subject of wiring is one which is of particular interest to all manufacturers' engineers. It has been said that when gas was first introduced into the Houses of Parliament pipes were laid on brackets several inches from the wall, presumably to prevent fire risk. This is not more absurd than some details enforced by modern wiring rules, and I remember having buried wires in fireclay contained in grooved casing, so as to reduce the fire risk. This was about twelve years ago, but the work was strictly carried out to the rules or specification of an insurance company. Mr. Gott.

The question arises as to what authority should formulate and enforce rules. Should not the station engineer's authority cease at the meter? As the leakage on one outer of a 3-wire system in the consumer's premises under certain conditions will even pay for the station leakage, I do not see why the station engineer need trouble about rules so long as the consumer does not affect the supply. The gas companies allow you to use as much gas as you like, and in any manner, but I do not wish to infer that we should have no rules whatever; rather, if rules are necessary let us have them uniform, embracing general principles and broad enough to facilitate progress. In the paper which Mr. Broadbent has given us, I think he has done a very bold work in bringing this subject up in a new form, and in showing the utter chaos that exists in modern rules.

Mr. Gott. It will be noticed that the rules of the Institution of Electrical Engineers express a fundamental principle of what rules should be. In the examples analysed in the paper we read at intervals that the rules will be enforced, but no responsibility is taken by the authorities concerned. This seems very unfair, particularly as some authorities, Manchester for instance, register and certify fittings, although the certificate is no guarantee that the particular article is the best for a particular purpose. Does Manchester test switches with self-induction in the circuit? It makes a vast amount of difference in the rating of a switch.

As an example of the difficulties of standardising, particularly motor accessories, it may be noted that there are in use in the kingdom no fewer than 16 voltages between 100 and 530, all of which are multiples of 10.

Motors under 1 H.P. at 500 volts are neither safe nor particularly desirable. Under the heading of main switches, manufacturers have a very sore grievance indeed. Double pole link switches are generally specified by the fire offices and the supply companies to be linked, but at the same time they are forbidden to use combustible material, with the result that there are a number of double pole switches on the market which have the two poles connected together by a metal bridge insulated, in some cases, by about $\frac{1}{16}$th of mica. Such a switch is unsafe in comparison to one in which the bridge is either fibre or wood. Some rules specify the amount of break, but none state the character of the break, which should be in such a manner that the arc is self-extinguished.

The rule limiting the current on a circuit to 100 amperes must limit the size of motors on the supply system's main, and many motors are in use on single machines taking very much greater currents than 100 amperes. Liverpool uses two meters and two sets of switches in parallel in such cases, but they cannot ensure that the current will divide equally between the two meters, and, as a matter of fact, it does not.

Considerable want of uniformity exists regarding the application of main switches at the point of entrance of supply into a building. It seems that, as gas and other companies put in a means of cutting off the supply, the electric supply companies ought to do the same—that is, to provide a main switch and fuse independent of any supplied by the consumer.

Such rules as specify front or back connections are quite unnecessary; the whole thing is a matter of convenience. If the switchboard is going against the wall the front connections are correct, but in a case where you can get behind it is sometimes preferable to do so. In Blackpool it is a rule that slates must be boiled in paraffin wax or similar insulating compounds, and afterwards enamelled. It would be interesting to know how to do it, as I understand that it is impossible to enamel a waxed slate. One thing never specified, and it is only an instance of overlooking important details, is to insulate the slates from the wood or metal frame.

Then in Tynemouth we have the rule concerning tumbler switches. Similar rules should state that the switch must be so fixed that in the

event of vital parts breaking the switch will remain off. Some rules forbid switch-holders. It might have been very well to do so half a dozen years ago. The switch lamp-holders of to-day are as reliable as desired. There are many instances in which articles are specified which do not exist. For instance, "heating sockets to be automatically covered when the plug is withdrawn." This is a sample of specifying something which has to be not simply designed, but invented, and this is a grievance with manufacturers. Mr. Gott.

Portables and flexibles are disallowed in shop windows by some rules. I might ask, are the fittings which are usually put into shop windows as safe? I think not always. Incandescent lamps in horizontal positions have been forbidden in many instances unless filaments are specially supported. This rule is based on the experience of a dozen years ago, but such a restriction is quite unnecessary at the present day. Lamps are better made, and if the legs of the filament are in a vertical plane the lamp is practically immune from breakage through the filament touching the glass. This matter should rest entirely with the consumer, and if such a rule were enforced, "display" work would be annihilated.

I think that it is quite unnecessary to specify the type of insulation provided that the conductor has got a satisfactory mechanical covering, and is insulated in a manner to satisfy the local conditions. A great many supply authorities copy the Institution of Electrical Engineers' rule relating to conductivity of the wire, which, however, conveys no meaning to the lay mind, and a much better rule would be that a copper wire 40 yards long, and ·001 sq. in. section or ·5 lb. weight should have a resistance of 1 ohm at 60° F. within 2 per cent. Every consumer would understand some such rule.

Then, the question of the 1-volt drop is decidedly an undue interference with the consumer's economics. Of course in shops and small installations the question does not enter at all if the conductors are to the recognised current density, but if the consumer is, say, a rope manufacturer, and requires half a dozen lamps at the end of his rope walk, it would be decidedly unfair to compel him to put in wires of a section to limit the drop to one volt. Large contractors are accustomed to deal with these matters in a more economical and satisfactory manner.

I think there is nothing in installations that requires greater judgment than the casing of wires. A method may be arrived at after very long consideration and prove a mistake, but I might ask if supply authorities never make mistakes in the matter of running their underground mains. What about the large quantity of bare or of rubber-covered conductors that are put in and then have to be pulled out again?

Regarding motors, the early Phœnix rules were so worded that they entirely barred progress in this country, as a motor was not allowed in the working room of a textile mill, and the direct-geared motor was entirely excluded. Authorities are divided on the question of earthing or insulating motors, and from the advocates of the latter it would be interesting to learn how a metal pinion is to be satisfactory insulated from the shaft. The definition of "earth" is most unsatisfactory, and a gas or water pipe does not always give a good earth.

Mr. Gott. It would be better to state that the "earthing" must be so carried out that there shall be no measurable difference of potential between the motor and the immediate surroundings with a certain current in circuit. Very stringest clauses exist concerning the current fluctuations in starting motors, and in the case of large motors the restrictions are excessive. One of 30 H.P. at 200 volts, starting under full load and driving an inert machine, would require no less than 80 sections of resistance in order accurately to satisfy the 10-ampere rule.

Flywheels are frequently specified for motors, and there is no doubt that they would frequently be an improvement, but the worst cases of varying loads are not infrequently with direct-geared motors to particular machines, where the application of a flywheel would most seriously affect the working of the latter. Too much stress has been made on insulation resistance, neglecting the fact that high insulation does not necessarily mean good work. The final resistance depends little upon the quality of the wire, but very much upon the care of jointing and cleanliness in fixing lamp-holders.

If there are to be rules we must have rules on broad principles, *and there must be uniformity.*

Mr. Falconar. Mr. O. L. FALCONAR: I think every one will admit that there is a very pressing need for the standardisation of wiring regulations, and Mr. Broadbent has so aptly described some of the inconsistencies which add considerably to the worries of the wiring contractor, that it is unnecessary to say anything further about them. There is one rule which just occurs to me at the moment which I may mention, viz., that requiring to be named all the various sizes of cables used of the installation, also the amount of current carried under normal conditions by each, and the percentage above this they will safely carry. The latter part of this question is especially difficult to answer correctly, as it varies considerably with the conditions under which they are used. Moreover, the insurance company themselves, if I mistake not, specify what current *can* be safely carried by the various sizes of conductors.

Mr. Broadbent seems to imply that, had there never been any wiring regulations issued, the advancement of electric lighting would have greatly increased; and I think there is some reason for this view being taken, for it is difficult to introduce novelties in electric wiring when the contractor has to obtain the consent of four or five insurance companies or other authorities. On the other hand, however, there is the unfortunate fact that all wiring contractors are not equally honourable, and with the progress of electric lighting the "jerry contractor" has come into existence. My opinion is, that if a set of standard regulations applicable to the various conditions of electric wiring could be drawn up, which clearly defined the essential conditions of a high-class installation without going into some of the details of which we have heard in regard to minor points, it would be greatly to the advantage of the whole industry. Even if such ideal regulations could be drawn up, there would be difficulty in enforcing them. A contractor may quote for a job and desire to execute a certain class of work, but he knows perfectly well that some one else will quote for a cheaper class and will probably get the job. The supply companies certainly

endeavour to keep wiring contractors up to the mark, and have inspectors for that purpose, but I think they attach far too much importance to the "Insulation Resistance Test," which will sometimes condemn a job, however well designed, and pass others altogether devoid of any system. Probably in the "Ideal" regulations referred to, this test would be modified to suit various conditions. Mr. Broadbent considers five-ampere circuits quite small enough on 220-volt. supply. I venture to think $1\frac{1}{2}$ amperes as specified in some rules none too small, as not only would you have (in the case of fuse blowing) a large number of lamps extinguished, but I think at this pressure it is possible for an arc to be struck across a twin flexible, and maintained with less current than would blow a five-ampere circuit fuse. Probably Mr. Broadbent was thinking only of the 60–80 volt. installations it used to be customary to employ in ship lighting. Mr. Falconar.

I was very much enlightened to hear that there are only two corporations, viz., Glasgow and Manchester, who have power to enforce their rules; but surely other corporations would refuse to connect up if their rules were not complied with—and is this not the same thing?

Mr. S. H. Gowdy: I would like to offer my thanks to Mr. Broadbent for his paper. It is perhaps one of the most interesting subjects the electrical contractor has to deal with, as it is before him continually in his daily experience. We have recently formed an Association of Electrical Contractors in Newcastle and Gateshead, to further trade interests generally, one of the objects of which is to aim at the standardisation of specifications with respect to contracts, to be used by architects, etc., when necessary. With this object in view, Mr. Cross and I set to work a few weeks ago to draw up a set of suitable rules, by extracting from existing, but after about three hours' work we had to give it up for the time as we found the rules of the various fire insurance companies so conflicting and contradictory. We are still but a short way on the long and crooked road to standardisation. We used the Royal Insurance Company's rules in the first place, as theirs are better classified than the other companies' rules, but not because we considered them the best set of rules. I would like to ask Mr. Broadbent why Glasgow and Manchester possess powers to enforce their rules when other towns cannot obtain these powers—the Newcastle Electric Supply Company manages to enforce its rules whether it has power to do so or not! Mr. Gowdy.

I am sorry Mr. Broadbent omitted to mention the specifications of architects and consulting engineers, which are very often as conflicting and exacting as any. In one consulting engineer's specification I know of, the sizes of blocks for switches and ceiling roses are stated, also the size and even the number and kind of screws to be used are specified. The blocks and switchboards have to be specially made, at about three times the usual cost. In another specification—an architect's this time—in one paragraph it says, "fuses only to be in the distribution boards and in ceiling roses," and the very next sentence says, "no fuses are allowed in the ceiling roses." The work has to be done in accordance with the rules of the several fire insurance companies with which the building is insured, of the supply company providing current, and of

Mr. Gowdy. the Institution of Electrical Engineers. It would be rather interesting to know how the contractor manages to satisfy these various authorities. I have been making inquiries of the fire insurance companies as to whether they issue any rules respecting gas and oil lamp installations, and find that they do not trouble about them. Personally, I should think it would be better for them if they did, as probably the number of fires caused by these means would be considerably reduced. It is interesting to read the report of the London Fire Brigade for 1899, which says that out of 622 fires, 312 were caused by gas, 292 by oil lamps, and 18 by electricity, and considering how rapidly the use of the latter is growing, I think my previous remark as to the advisability of adopting rules for gas and oil work was well founded. Referring to the use of aluminium as a conductor, the American Underwriters National Electrical Association reported recently that insulated aluminium wire has a safe carrying capacity of 84 per cent., that of similarly insulated copper wire of the same size, while bare aluminium has only 77 per cent. the capacity of the corresponding size of bare copper wire.

I do not remember seeing aluminium mentioned in any Fire Office rules, though there is no reason why it should not be used under certain conditions. With regard to the tree system, I have come across installations with cut-outs dotted all over the building, such as under floors, on high ceilings, and, in churches, up in the roof—which positions are not, of course, the most convenient and accessible in which to renew a fuse. There is no doubt that this system should be abolished, and that standardisation both in system and material (to a certain extent at any rate) is what we should aim at obtaining, and I think it will come before very long.

Mr. Sleigh. Mr. JOSEPH P. SLEIGH: To get over the difficulty of making wiring and motor regulations uniform, I would suggest that central station engineers combine and have a central committee, who can revise and standardise rules submitted to them by the engineers of individual stations, or, if need be, provide a complete set of rules on being furnished by the engineer with particulars of his system and the local conditions to be met. This committee not being a local body, and hence having no local interest, would be able to deal with each individual case on general principles and thus eliminate any personal fads due to the engineer's particular line of experience. This question might be taken up by the Municipal Electrical Association, but it would be more comprehensive if taken up by the Institution of Electrical Engineers. With regard to Fire Office rules, these could be brought to uniformity by the above committee approaching all the fire insurance companies and getting them to issue a standard set of rules. With regard to specifications issued by architects and persons not competent to do so, and on which contractors have to quote, this is clearly a case to be met by the Contractors' Association. Members of the association would have to take a firm stand, and all quote on certain definite lines laid down by the association, and, if need be, in particular cases the committee of the association should be referred to.

Mr. Broadbent. Mr. BROADBENT, in reply, said: I am bound to say that I am somewhat disappointed with the discussion. I hoped that the station

Mr. Broadbent

engineers would have attempted to defend and to justify their rules, and their attitude to contractors generally, whereas they all agree generally with my paper.

In criticising any paper, it is necessary first of all to know its contents. Some of the speakers have criticised things I did not say, and misconstrued what I actually said. Mr. Turnbull's is "the unkindest cut of all," as he criticises my objection to standardisation! Now, the sole object of the paper is to plead for standardisation in so far as it is possible. In my preliminary remarks I referred to the danger of mistaking standardisation for progress, and making it an end instead of a means to an end. Mr. Turnbull says that the firm which standardises most will be found most progressive. I think he falls into the pit I intended to warn you against. He mistakes *repetition* for *standardisation* and *money-making* for *progress*. Repetition obviously hinders progress, and when any progress is made, "wholesome scrapping" becomes a necessary evil—not a virtue as we are sometimes led to believe.

I did not quite follow Mr. Turnbull's remarks about red and black wire. I certainly have no objection to it, and used it over twelve years ago to distinguish between the lead, or switch wire, and the return. This is what I understand Mr. Turnbull to say was his practice also. But, as his is a three-wire system, this involves either putting switches on the *earthed* middle wire on one side of the system, or, using one colour for the outers and another for the middle, which would cause confusion. Further, in a motor installation wired from the outers only, one colour could, of course, only be used, so what becomes of the "red and black" rule? Mr. Gowdy and others question my remarks that, with the exception of Glasgow and Manchester, no other corporation or company have the power to enforce their rules, and ask how these two authorities became possessed of the power. In the case of Manchester, a clause was smuggled through Parliament in the Omnibus Act known as "The Manchester Corporation Act, 1897," whilst in the case of Glasgow powers were similarly obtained by means of "The Glasgow Buildings Regulation Act, 1892."

So far as I am aware, the only powers possessed by any other authority are those given in certain clauses of the Board of Trade model provisional order. Under these clauses the undertakers are bound to supply energy to any consumer, provided that they are "satisfied that the electric lines, fittings, and apparatus are in good order and condition, and not calculated to affect injuriously the use of energy by the undertakers or by other persons." The undertakers may cut off the supply if a consumer uses his energy in such a way as unduly or improperly to interfere with the efficient supply of energy to any other consumer. Now, I contend that switching on or off ten amperes, at, say, 230 volts, is not an improper use of the energy, and if this interfere with any other consumer's supply it is the fault of the undertakers. A point for consumers to remember is, that if the undertakers make default in supplying energy to any consumer, they are liable to a penalty not exceeding forty shillings for each day on which such default occurs.

Mr. Gowdy is in error in saying that there are no rules for gas-pipes

Mr. Broadbent.

and fittings. In the case of Manchester, there is a book containing forty-two rules and seventeen conditions of supply.

There is, I think, nothing in the other speakers' remarks calling for reply; the general tone of the discussion is in agreement with the paper. My feeling is that the task of standardising all the existing rules will prove too great for the committee appointed by the parent body, and that it would simplify matters considerably if each Local Section would standardise the rules in its own district. The headquarters committee could then deal with Local Section draft rules, which would be found to be in fairly close agreement. This is work which I think the Local Sections might very fittingly take up, and if the meeting agrees, I should be pleased to put this in the form of a motion.

[*Communicated.*] I have since seen the report of Mr. Turnbull's remarks, and find that he makes the *live* wire the red wire, whereas in his rules he specifies red for positive and black for negative. In the former case red wire only would be used on a 460-volt installation, and in the second case he would have two colours for his earthed middle wire, and on the negative side of the system the switches would cut off the earthed wire instead of the live wire.

ORIGINAL COMMUNICATION.

THE RISE OF TEMPERATURE IN THE FIELD COILS OF DYNAMOS.

By E. Brown, M.Sc., Associate, 1851 Exhibition Science Scholar.

This communication describes the results of experiments recently made by the author, on the question of the rise of temperature in the field coils of a dynamo under various conditions. So far as the author is aware, very few experimental results dealing with this subject have been published, and since the subject is of scientific as well as of considerable practical interest, this series of experiments was undertaken.

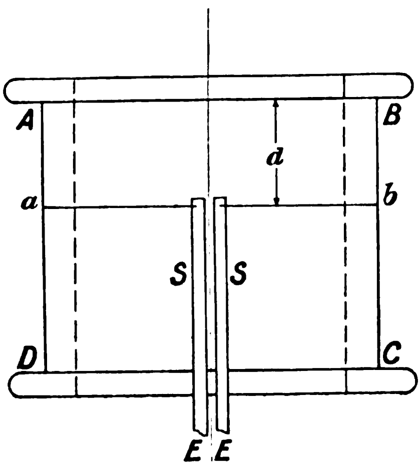

Fig. 1.

The experimental work has been carried out at the City and Guilds of London Central Technical College. At Professor Ayrton's request, Messrs. Siemens Bros. very kindly placed at the author's disposal one of their machines, the output of which is 55 amperes at 135 volts at a speed of 1,250 revolutions per minute. The armature is of the

smooth-core drum type. Plate XVII. shows a general view of the machine.

To obtain a true conception of the temperature distribution throughout the field coil, it is necessary that the temperature at different points along the axis of the coil at different depths in the winding be determined.

The method adopted to measure the temperature was the use of resistance thermometers. Let A B C D (Fig. 1) represent the elevation of the field coil after a certain number of layers of wire have been wound on. To deter-

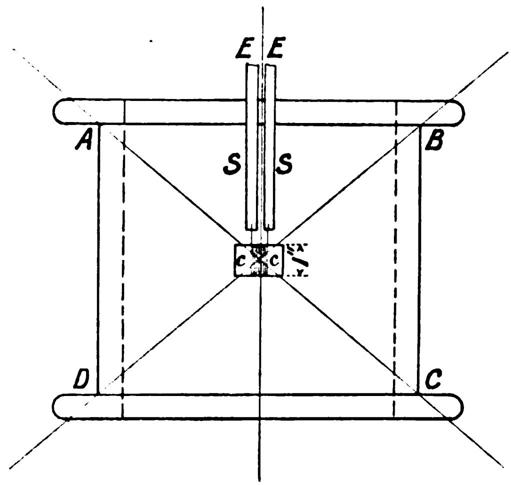

FIG. 2.

mine the temperature at this layer at a distance d from the top of the bobbin, a length of wire, whose temperature coefficient and resistance at some particular temperature are known, was taken and placed round the coil so as to completely embrace it at the given distance from the top. The ends of this wire were soldered to copper strips SS of negligible resistance, which were placed flat along the surface of the coil. The ends EE of these strips dipped into mercury cups on a terminal board placed near the machine.

By placing a number of such thermometers in different positions along the axis of the coil, at different depths in the winding, a means is provided of ascertaining the temperature distribution throughout the coil.

The temperature thus measured is the average temperature taken round the coil at the given positions. Any difference of temperature which might exist at the same depth in the winding, between the side of the coil adjacent to the neighbouring field-magnet coil and the other side

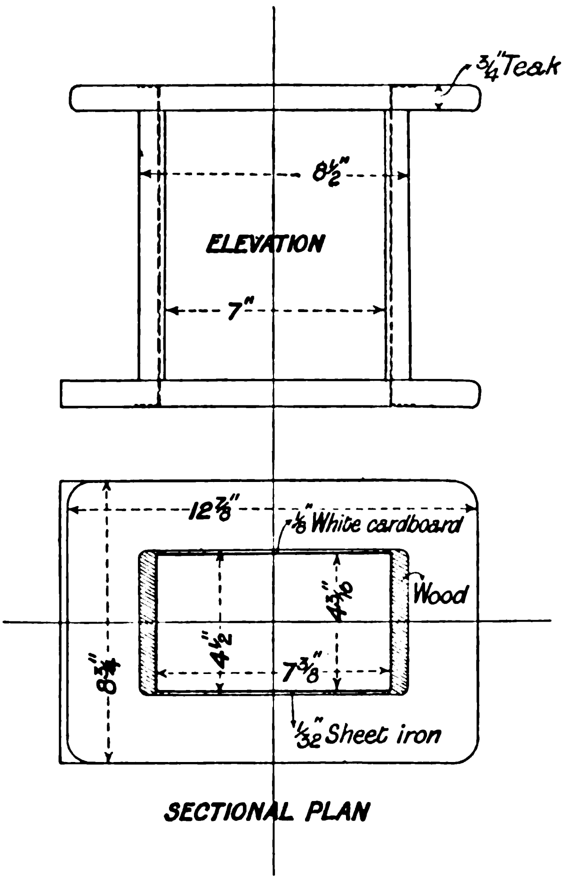

FIG. 3.

directly exposed to the air, would not be indicated. With the object of ascertaining whether any such difference existed, two thermometers of a different type were inserted as under :—

Let A B C D (Fig. 2) represent the elevation of the field coil at any given depth in the winding. Fine copper wire

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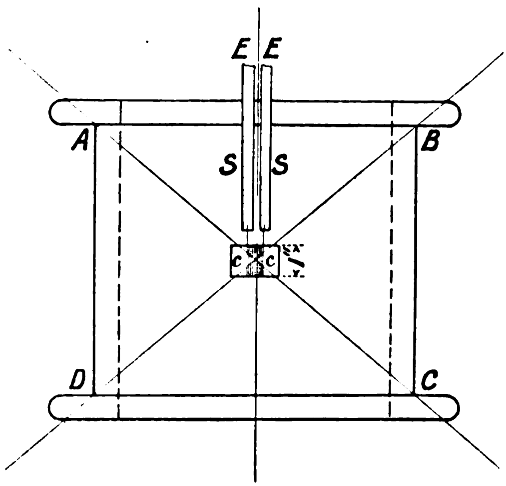

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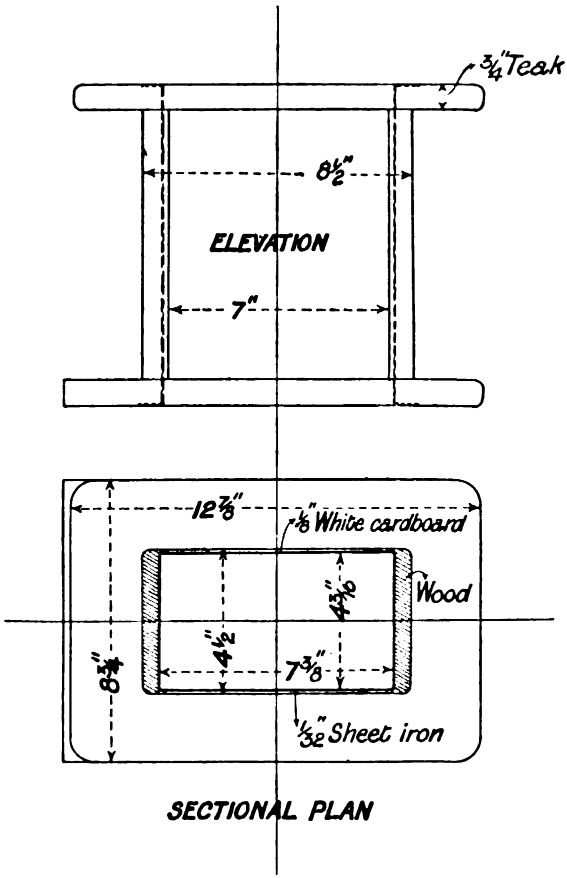

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Let A B C D (Fig. 2) represent the elevation of the field coil at any given depth in the winding. Fine copper wire

was wound on two very thin cardboard strips, CC, one inch wide, the ends of the wire being soldered to copper strips as before. These flat thermometers were placed on opposite faces of the coil over the same layer of the winding as shown in the figure.

In the experimental coil the number of thermometers was limited to fourteen, in order that their presence might not unduly throw the coil out of shape. The fourteen include the two flat ones just described, together with twelve completely embracing the coil, the latter being disposed in sets of four at each of three different depths in the winding.

Details of the Experimental Field Coil.

Fig. 3 shows the construction of the bobbin, which was constructed to take the place of the one belonging to this machine, the dimensions under the first layer of the winding being as indicated. The winding consists of five layers of wire 0·0512 inch diameter, and seventeen layers 0·0551 inch diameter, double-cotton covered, as in the actual coil of the machine. The total number of turns is 2,587, and the radiating surface (neglecting the ends) is 289 square inches.

The disposition of the thermometers is shown in Fig. 4, in which they are indicated by black dots. The respective distances of the inner, mid, and outer layers from the surface of the bobbin are 0·07 inch, 0·94 inch, and 1·44 inch. The flat thermometers are inserted at a distance 0·62 inch from the surface of the bobbin. The total depth of winding is 1·6 inch. The upper three thermometers of each layer are of platinum, the others being of copper.

The temperature coefficients of the thermometers were determined after the winding of the coil was completed. The coil, along with its mercury terminal cups, was placed in a large copper vessel surrounded by water and screened from outside radiation effects by non-conducting materials. It was allowed to stand a sufficiently long time to ensure a uniform temperature being reached. The resistances of the thermometers were carefully measured, and from such measurements made at different temperatures the temperature resistance curve of each thermometer was determined.

In the actual experiments with the coil the resistances

of the thermometers were measured by a slide-wire Wheatstone's bridge. Time readings of the temperatures of each thermometer were plotted, and the temperatures of all the thermometers at any given instant deduced from these.

A voltage sufficiently high to enable the field coils to be connected in series not being available, they were connected in parallel. A current of 2·5 amperes was maintained

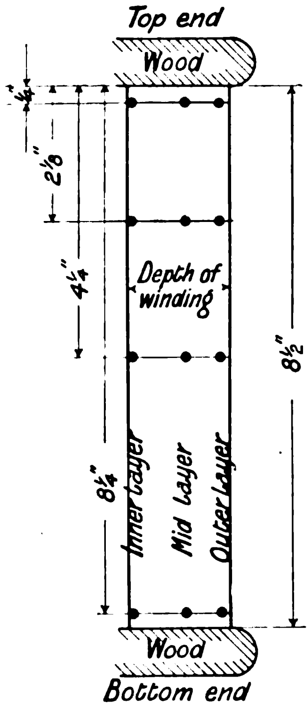

FIG. 4.

throughout the experimental field coil throughout the experiments. Fig. 5 shows the arrangement adopted.

It was noticed at an early stage of the work that when the armature was rotating, one of the field coils received a much stronger current of air across its surface than the other. Thus, if in Fig. 6 A represents the armature, the direction of rotation as seen from the commutator end of the machine being as shown, it was found that the coil F_1 was much more vigorously fanned than F_2. This is due to

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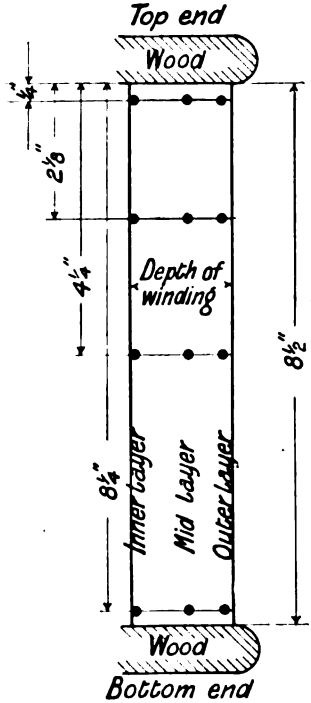

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the action of the commutator guard GG, which extends a considerable distance below the horizontal diameter of the commutator, and which, although perforated, acts as a vane, or guide, directing the air current across F_1 as shown by the arrow. At a speed of 1,200 revolutions per minute a lighted taper held at K continued to burn, its flame being drawn in the direction F_1, but when held at L it was at once extinguished. Hence there will probably be a different temperature distribution if the position of the coil on the limb of the machine is altered. Accordingly two sets of experiments were made, one in which the experimental coil was in the position F_1, and the other in which it was in the position F_2.

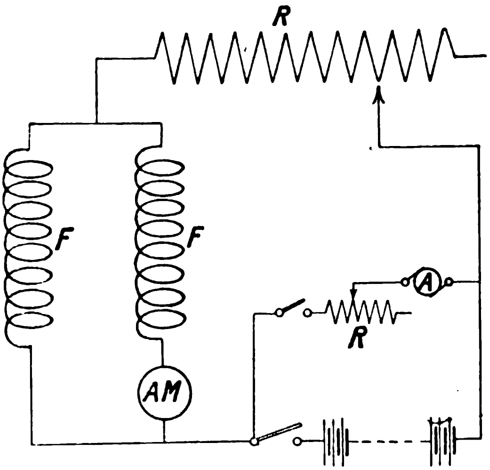


FIG. 5.

F F. Field coils.
A. Armature.
A M. Ammeter.
R R. Adjustable resistances.

When in the former position it will be subsequently referred to as being *directly fanned*, and when in the latter position as being *indirectly fanned*.

With the coil in each of these positions experiments were made under the following conditions :—

(*a*) Armature running light.
(*b*) " carrying 30 amperes.
(*c*) " " 55 "

In each of these cases four different armature speeds, viz., 300, 600, 900, and 1,200 revolutions per minute, were used. The variations in armature current and speed were kept within narrow limits by the use of adjustable resistances.

From these experiments curves have been plotted showing—

1. The effect of increase of armature speed on the rise of temperature along the three vertical layers of the winding, in the conditions of armature load (*a*), (*b*), and (*c*).

2. The effect of increase of armature speed on the rise of temperature through the horizontal depth of winding at points halfway along the axis of the coil, in the conditions of armature load (*a*), (*b*), and (*c*).

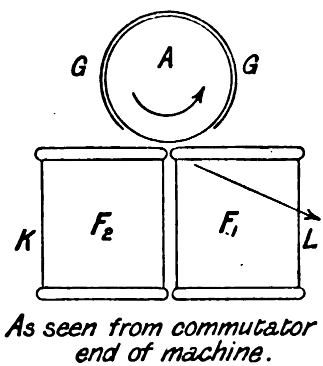


FIG. 6.

3. The effect of increase of armature current on the rise of temperature along the three vertical layers of the winding, under the four different armature speeds of 300, 600, 900, and 1,200 revolutions per minute.

In all experiments the machine ran as a motor. To avoid the heating effects which the application of a friction dynamometer to absorb the power developed would have produced, when the armature current was 30 and 55 amperes the motor pulley was belted with that of a dynamo supplying the greater part of current required to drive the motor. The additional current was supplied from the street mains, and in all cases the field coils of the motor were separately excited from storage cells.

In the plates showing the temperature distribution along the axis of the coil, the scale of the depth of winding has been exaggerated.

Directly Fanned Coil.

Consider first the set of curves dealing with the cases in which the coil was *directly fanned.*

1. Plate I. shows the effect, at different layers of the winding, of increasing the speed of rotation of the armature when the armature is running light.

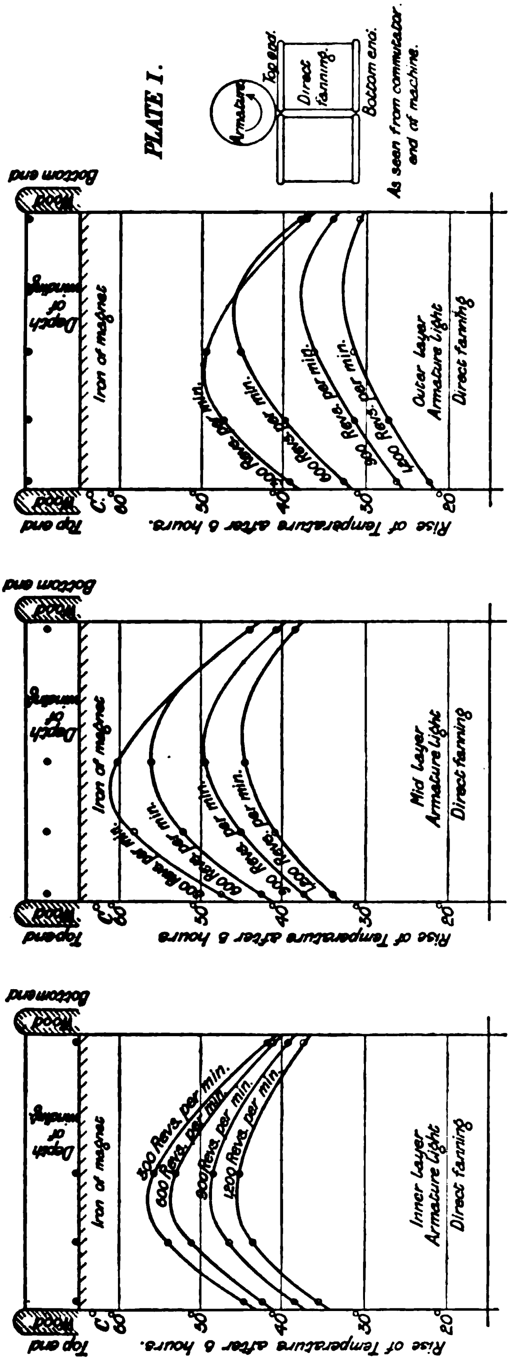
The concavity of the curves is a very noticeable feature. It is more particularly evident when the speed of rotation is low, and is always most marked at the mid layer. As the speed of the armature increases, the concavity diminishes, the difference between the temperature rise at 300 revolutions per minute and that at 1,200 revolutions per minute being less at the ends of the coil than at points nearer the mid position along the axis. Concavity is a feature of all the curves which have been obtained, and will be again referred to after the series of curves has been examined.

The effect of increased speed of rotation is most evident at the top of the coil, and the amount of cooling produced by any increase of speed is greater at the outer layers than at layers nearer the iron of the magnets. The bottom end of the coil is much less affected by the convection currents set up by the rotation of the armature, than the top end. It will be seen that at 1,200 revolutions per minute the top end is cooler than the bottom end, while at 300 revolutions per minute the reverse is the case.

A further effect of increased speed is the driving of the point of maximum temperature, at any layer, along the axis of the coil from the top towards the bottom end. The effect is most noticeable at the outer layers.

It may be mentioned that the mid layer is not the hottest layer of the winding. Later curves showing the temperature gradient through the depth of the winding show that the hottest layer is nearer the iron than the mid layer.

The crossing of the curves referring to the outer layer for speeds of 300 and 600 revolutions per minute, along



NOTE.—The Positions of Thermometers at different Layers are indicated on the Curves by black dots.

with other similar effects in subsequent curves, will be discussed later, as it was the subject of further experiment.

2. Plates II. and III. show the effect of increased speed of rotation of the armature, when the armature carried currents of 30 amperes and 55 amperes respectively.

The general effects of increase of speed are the same as when the armature is running light (Plate I.).

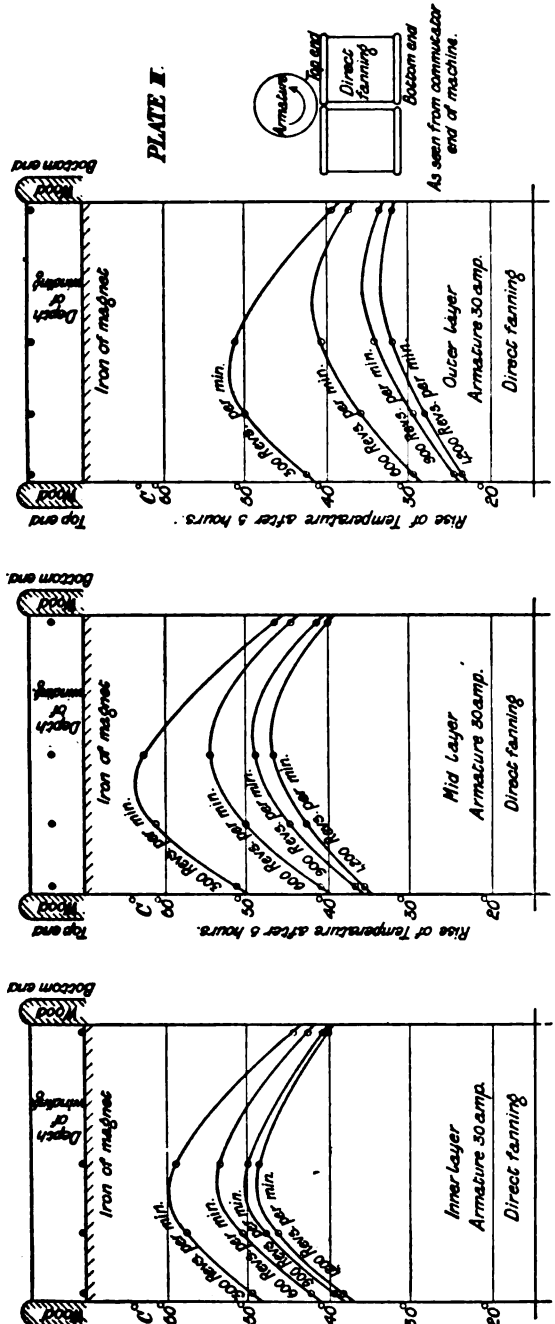
The rise of temperature at the lower speeds of rotation is rather high in parts of the coil, but the conditions of running (*i.e.*, about one-quarter normal speed, and full load armature current) are abnormal. The proximity of the heated armature to the top end of the field coil is undoubtedly the cause of the high rises of temperature observed in several cases.

The curves for speeds of 300 and 600 revolutions per minute again cross at the bottom end of the coil. There appears to be an intensification of this effect which was noticed in Plate I.

3. Plate IV. shows the effect of increased speed of rotation of the armature, on the rise of temperature through the depth of the winding, *at points situated halfway along the axis of the coil*, according as the armature is running light or with currents of 30 and 55 amperes.

The temperature gradient through the depth of the winding being of such great importance in considering the radiation of heat from the coil, a note is here necessary as to the method by which the curves are obtained. Of the four points plotted, three are determined from the readings of the thermometer placed in a horizontal plane in positions halfway along the axis of the coil, at the inner, mid, and outer layers (Fig. 4, p. 1163). The fourth point is given by the readings of the two flat thermometers (Fig. 2, p. 1160) inserted in the winding between the inner and mid layers. It may here be mentioned that no difference of temperature has been observed between these thermometers in any of the experiments. Hence it may be said, that (at any rate at that particular depth of the winding) there is no appreciable difference of temperature between the side of the coil facing the neighbouring field coil, and the side exposed to the air directly.

Although these flat thermometers extend half an inch



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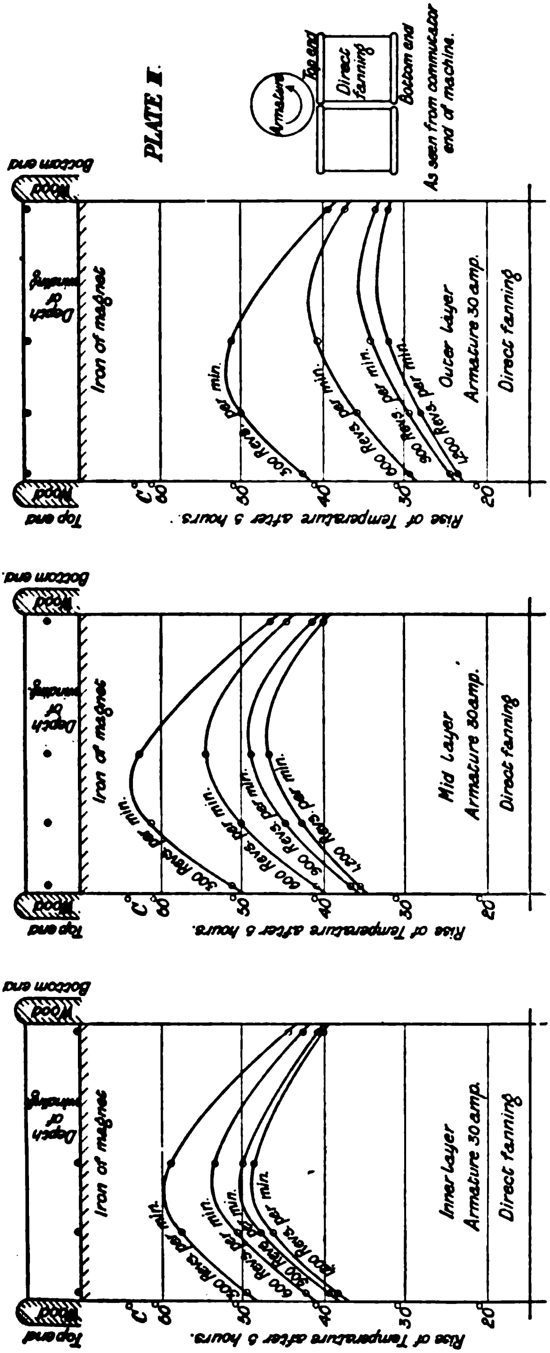

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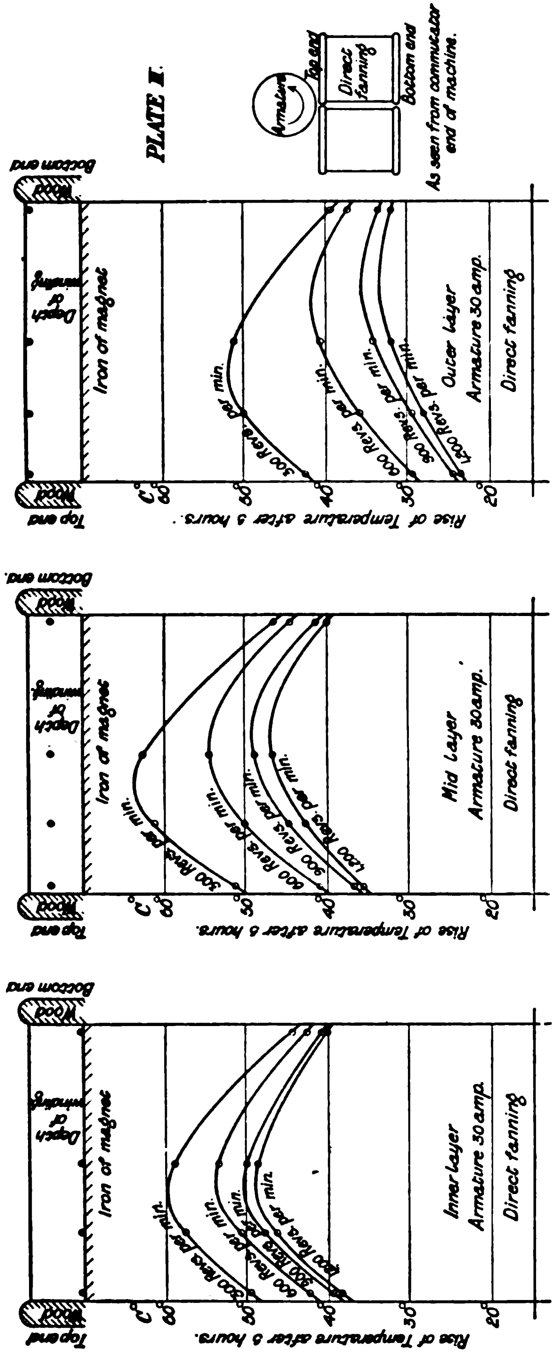

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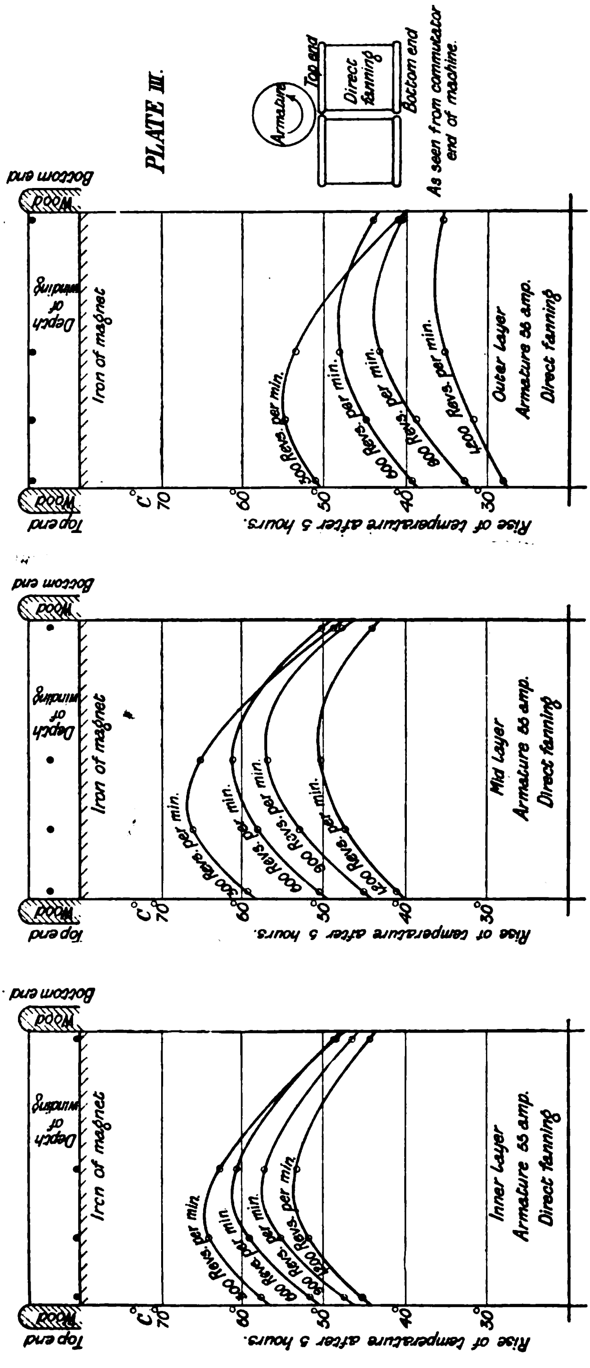

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on either side of the mid point along the axis, yet the rise of temperature indicated by them may be taken as the rise of temperature halfway along the axis. For the rise of temperature along the axis is represented by some such curve as in Fig. 7. The flat thermometer measures the average temperature over a length *a*, *c*, *b*, which is practically the actual temperature at the mid point along the axis. A fifth reading would have enabled the maximum

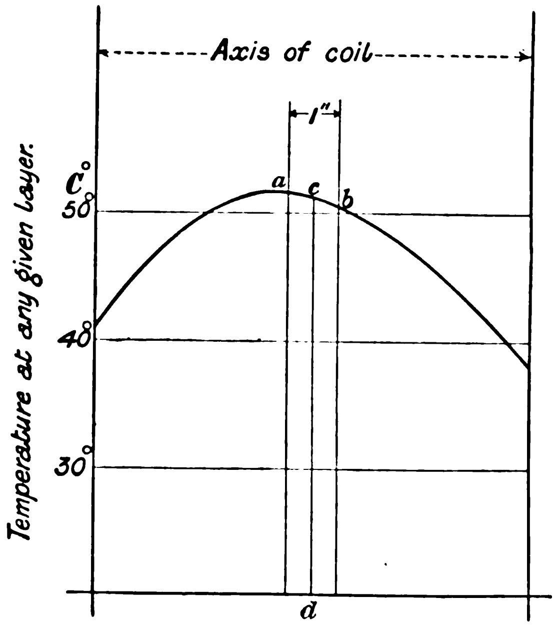
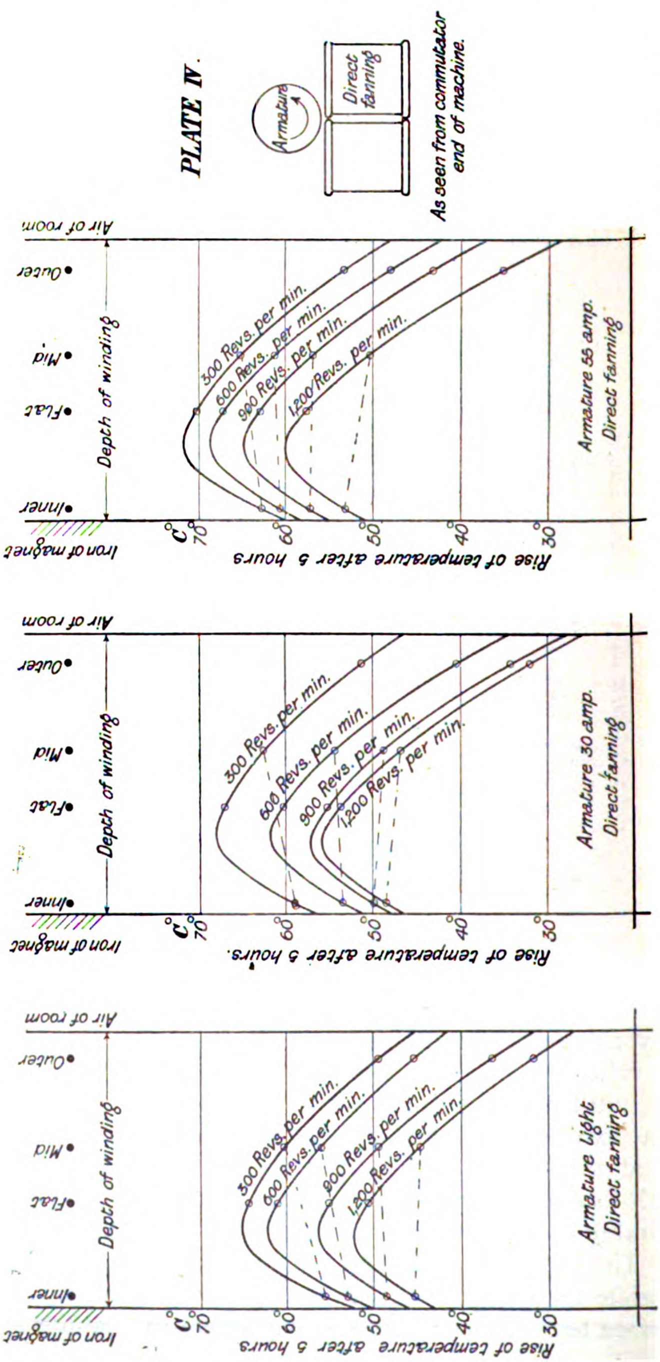


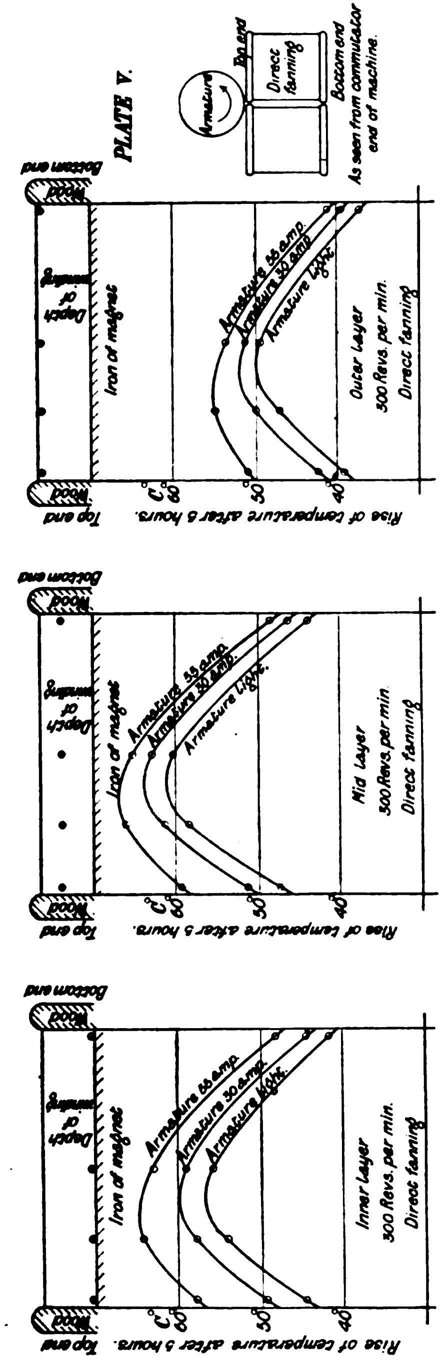
FIG. 7.

temperatures to be determined with greater accuracy, but the maxima shown are probably not far removed from the correct values.

The most striking feature of the curves is the high maxima exhibited, particularly when the armature was loaded at the lower speeds of rotation. Under approximate full-load conditions (55 amperes at 1,200 revolutions per minute) the maximum rise of temperature was about 60° C. The average rise through the depth of winding was 50° C, while the surface rise was 29° C. Such figures show that surface temperature readings may prove misleading as



NOTE.—Curves refer to Points situated half-way along the Axis of the Field Coil. The Positions of Thermometers are indicated by black dots.



NOTE.—The Positions of Thermometers at different Layers are indicated on the Curves by black dots.

to the actual temperature within the coil itself. *There is, in fact, quite as large a difference of temperature between the hottest part of the winding and the surface of the coil, as there is between the surface of the coil and the air of the room.*

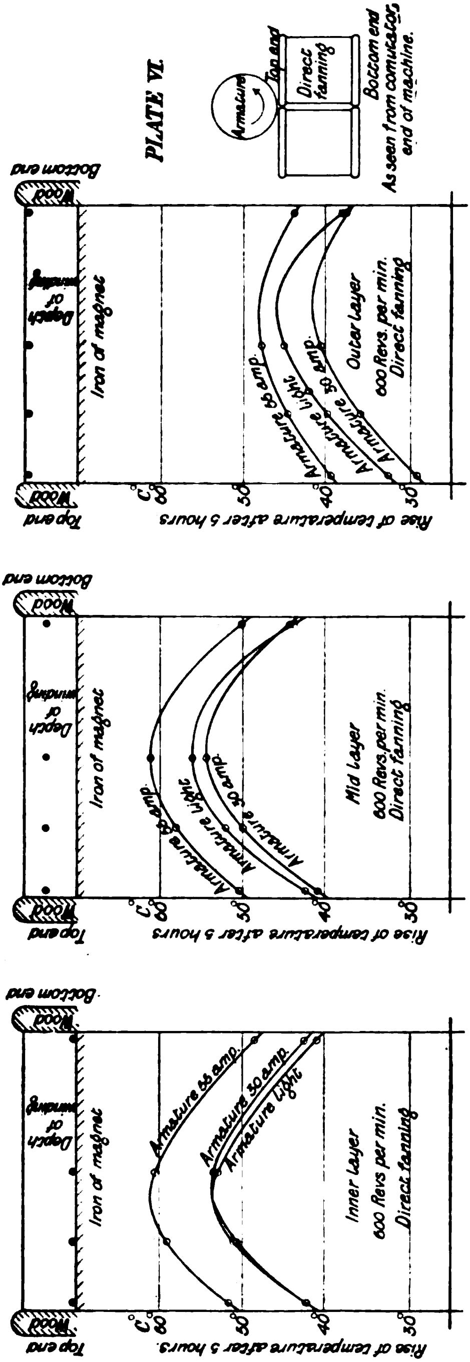
The hottest layer of the winding is about one-fourth of the total depth of winding from the inner layer. The magnet cores thus play an important part in the removal of heat from the coil. Not only do they remove heat from about one-fourth of the winding, but that fourth is much hotter than a fourth near the surface, and consequently the rate of heat production in it is greater than in the latter case.

Increase of armature speed is accompanied under all conditions of armature load by an increase of temperature gradient to the surface of the coil, because the cooling effects due to increase of speed are most marked at the outer layers, and diminish through the depth of the winding as the iron is approached. This is clearly shown by the dotted lines. At 300 revolutions per minute the mid layer is hotter than the inner layer, while at 1,200 revolutions per minute the reverse is the case. The temperature gradient to the surface of the coil is greater when the armature is loaded than when it is running light, the speed of rotation being unaltered.

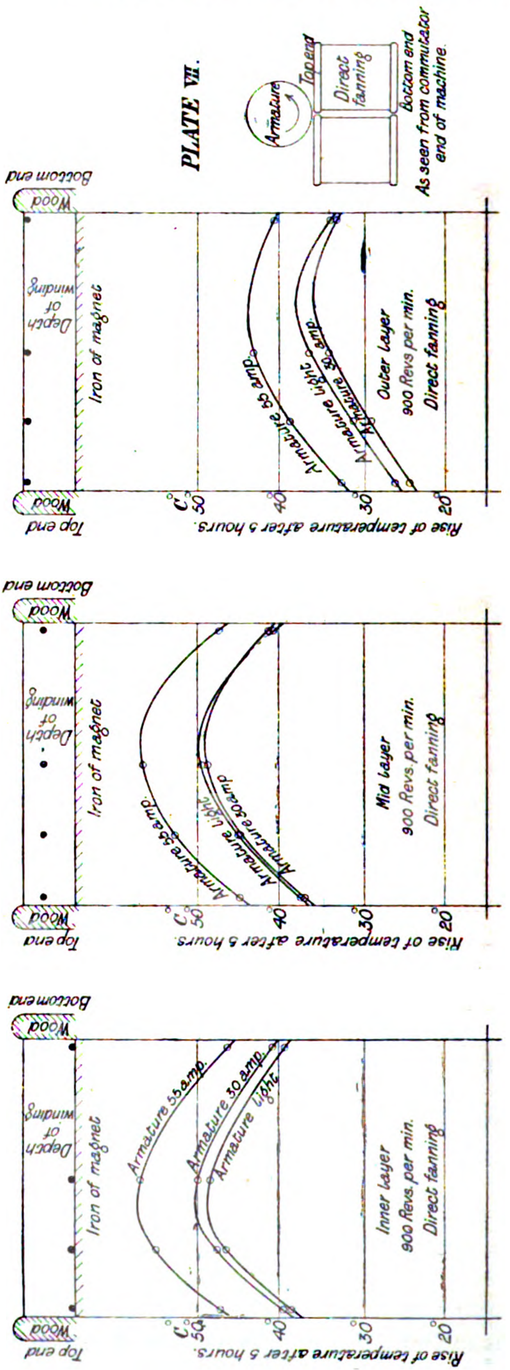
4. Plates V., VI., VII., and VIII. show the effect of changes of armature current on the rise of temperature in the coil at speeds of 300, 600, 900, and 1,200 revolutions per minute respectively.

At 300 revolutions per minute increase of armature current is in all cases accompanied by increased rise of temperature. The temperature gradients to the top end of the coil diminish as armature load increases, the temperature gradients to the bottom end being but little affected. This is probably due to the heating of the magnet cores by radiation from the armature. The iron at the bottom end being less subject to this effect than that at the top end, its efficiency in the removal of heat from the coil would be little impaired.

The increased rises of temperature accompanying increase of armature current are more marked at the inner than at the surface layers. This accounts for the increase



NOTE.—The Positions of Thermometers at different Layers are indicated on the Curves by black dots.



NOTE.—The Positions of Thermometers at different Layers are indicated on the Curves by black dots.

of temperature gradient to the surface of the coil through the depth of the winding when the armature load is increased, which was noticed in Plate IV.

At 600 revolutions per minute (Plate VI.) at the mid and outer layers, more particularly at the latter, the temperature rise is less when the armature load is 30 amperes than when it is running light. A similar but less marked effect is seen in Plate VII. at 900 revolutions per minute. At 1,200 revolutions per minute increased armature current is always accompanied by increased rise of temperature (Plate VIII.). This matter will be subsequently referred to.

Speaking generally, it may be said that increase of armature current diminishes the concavity of the curves, the speed of rotation being unaltered.

It may be said *that with reference to the directly fanned coil*—

(*a*) There is a marked concavity in all curves showing the rise of temperature along the axis of the coil at any particular layer of the winding.

(*b*) Increased speed of rotation of the armature considerably reduces this concavity, under all conditions of armature load.

(*c*) While the temperature gradient to the end surfaces is thus reduced, increased speed of rotation increases the temperature gradient through the depth of the winding, under all conditions of armature load.

(*d*) For any given speed of rotation the temperature gradient through the depth of the winding is increased by increase of armature load.

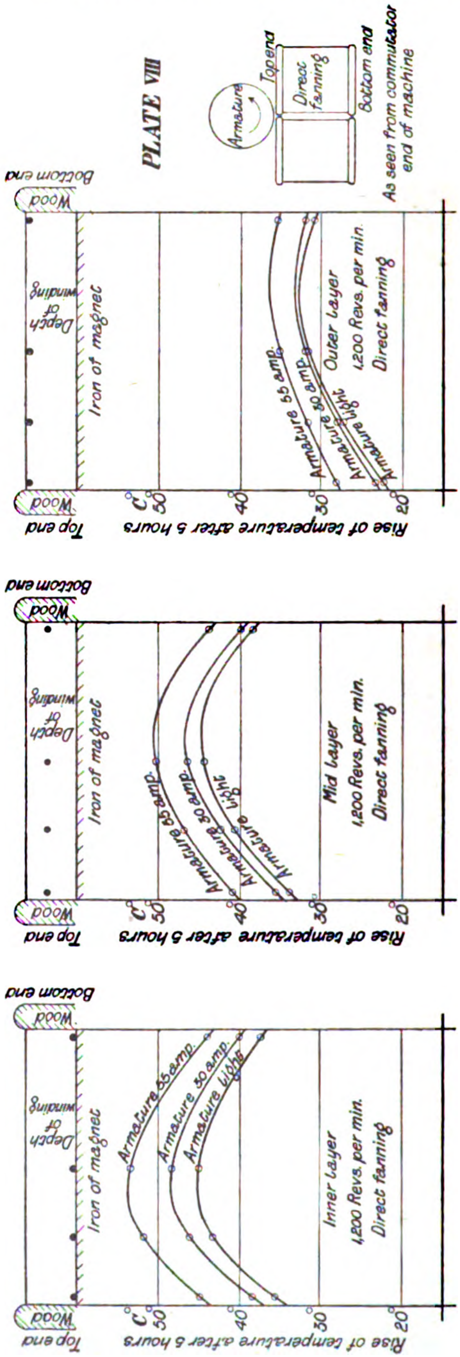
Indirectly Fanned Coil.

Consider now the curves obtained when the coil was *indirectly fanned* (Fig. 6, F_2, p. 1165).

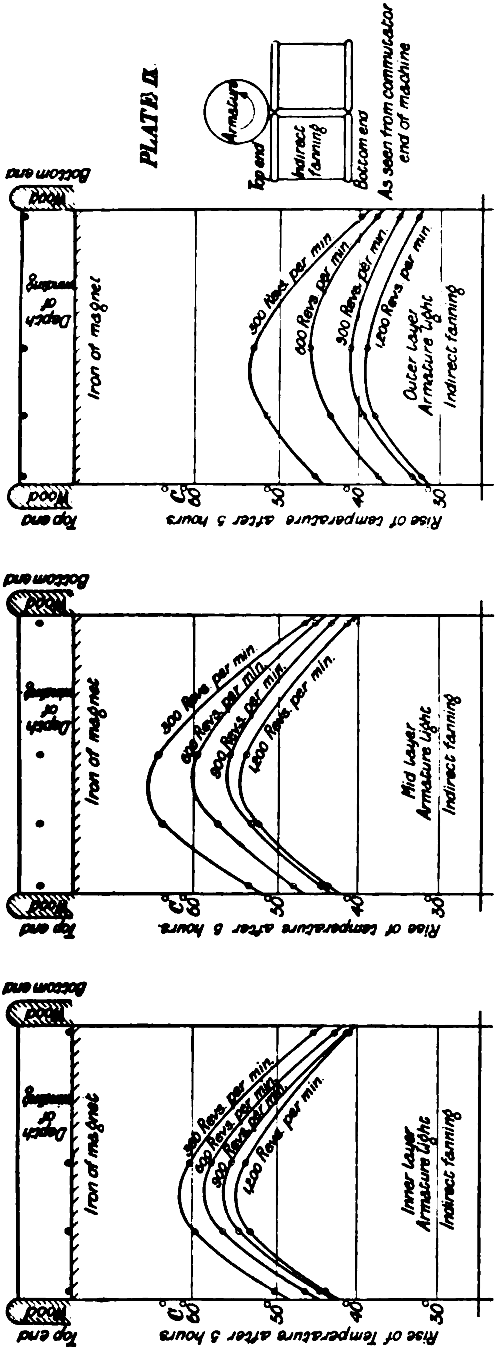
1. Plate IX. shows the effect of increase of speed on the rise of temperature at different layers of the winding when the armature is running light.

Concavity is again exhibited. The effects of increased speed are the same in general character, although less in

PLATE VIII



NOTE.—The Positions of Thermometers at different Layers are indicated on the Curves by black dots.



NOTE.—The Positions of Thermometers at different Layers are indicated on the Curves by black dots.

extent, than in the corresponding case with direct fanning (Plate I.). The cooling effects at the top end of the coil are not nearly so great as in the latter case, and it is not until a speed of 900 revolutions per minute is reached that the top end of the coil becomes cooler than the bottom end. The rises of temperature are greater than when the coil was directly fanned. These differences of rise of temperature increase as the speed increases, the strong currents of air set up at the higher speeds acting very beneficially on the directly fanned coil and less beneficially on the indirectly fanned coil.

2. Plates X. and XI. show the effect at different layers of the winding of increasing the speed of rotation, the armature currents being 30 amperes and 55 amperes respectively.

The general features are the same as those exhibited in Plate IX. The temperature rises are greater than in the corresponding with direct fanning (Plates II. and III.).

Concavity diminishes as the speed is increased, but the cooling effect is more uniform along the axis of the coil than in the case of direct fanning, in which the localised fanning at the top end of the coil resulted in a far from uniform cooling action.

A comparison of Plates IX., X., and XI. with Plates I., II., and III. shows that at 300 revolutions per minute the temperature distribution is much the same in the cases of direct and indirect fanning, and the temperature rises are little different. But at 1,200 revolutions per minute the temperature distribution is quite different in the two cases, although there is little difference in the *average* temperature rise.

The following table shows that for a given speed, when the armature is running light there is a considerable difference in the rise of temperature in the cases of direct and indirect fanning, but that as the armature load increases this difference diminishes, an equalisation of temperature between the coils resulting :—

Armature speed, 1,200 revolutions per minute.

Armature Current.		Average Rise of Temperature along Axis.		
		Inner Layer. °C.	Mid Layer. °C.	Outer Layer. °C.
Light	Direct fanning ...	42·0	41·6	29·8
	Indirect „ ...	49·5	49·3	36·8
30 amp.	Direct fanning ...	45·2	43·2	30·3
	Indirect „ ...	47·3	46·0	33·8
55 amp.	Direct fanning ...	49·9	47·4	34·0
	Indirect „ ...	51·5	49·5	37·2

The cooling of the indirectly fanned coil which takes place when the armature current is increased will be again referred to.

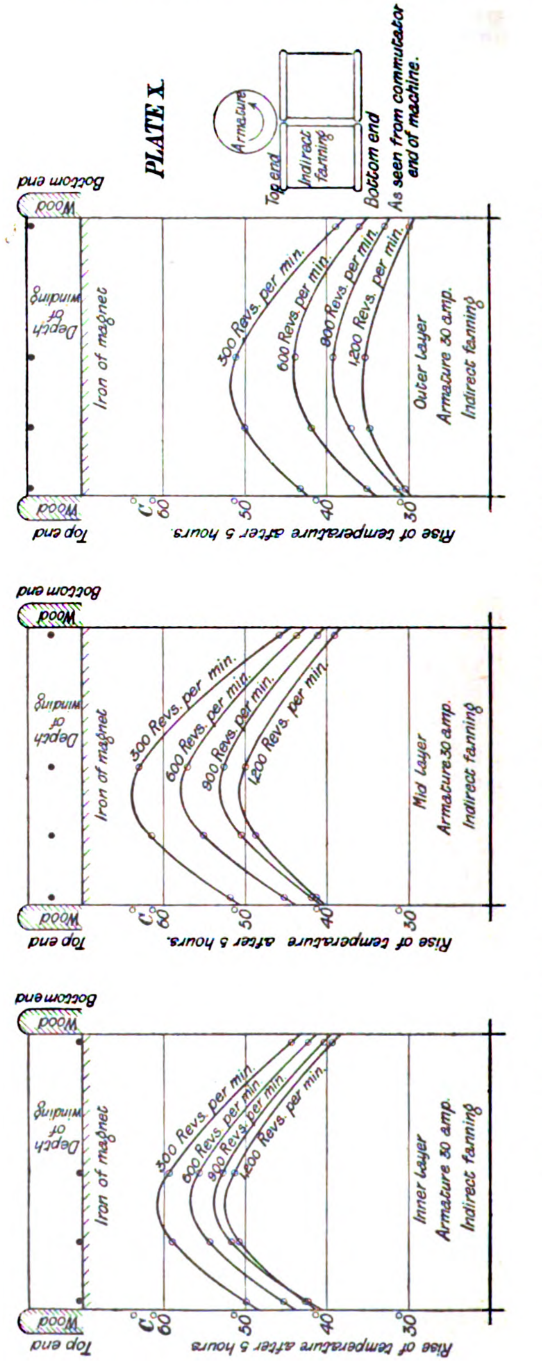
3. Plate XII. shows the effect of increased speed of rotation on the temperature rise through the depth of the winding, at points situated halfway along the axis of the coil, according as the armature runs light or with a current of 30 or 55 amperes.

The high maxima are again prominent features of the curves, particularly under the abnormal conditions. Under approximately full-load conditions (armature current 55 amperes, at 1,200 revolutions per minute) the maximum rise through the depth of the winding at this distance along the axis of the coil is about 62° C. The average rise as given by the curve is 52·5° C., while the surface rise is 32·8° C. These figures show what *a large difference of temperature there is between points inside the winding and the surface of the coil.*

Under any conditions of armature load increased speed of rotation is accompanied by increased temperature gradient to the surface of the coil.

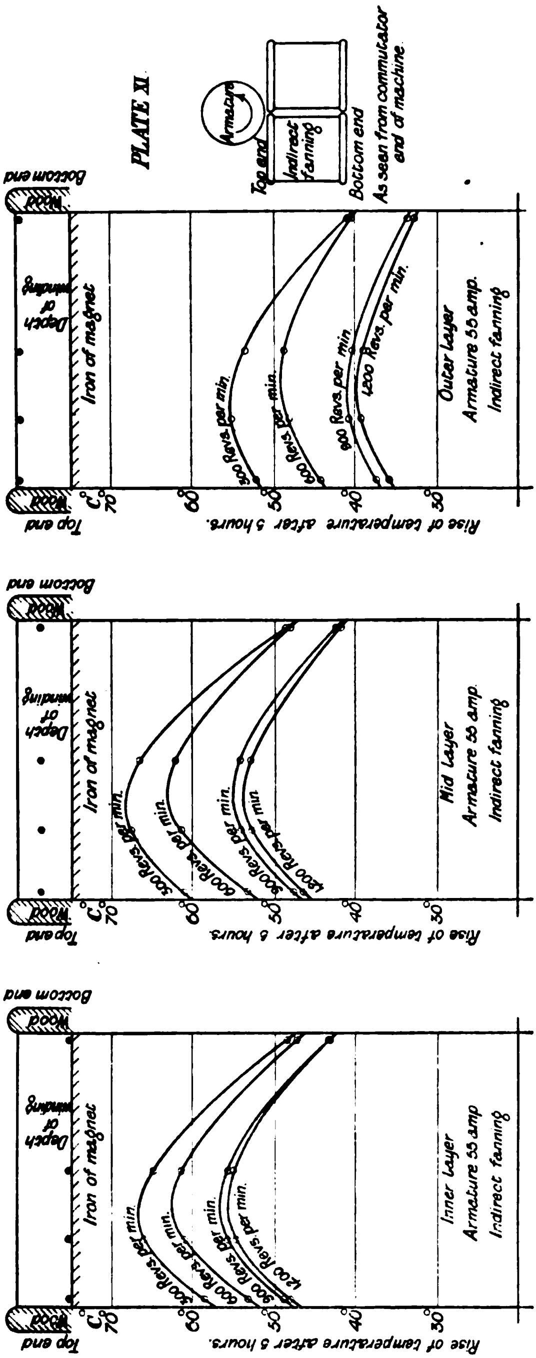
4. Plates XIII., XIV., XV., and XVI. show the effect of changes of armature current on the rise of temperature at different layers of the winding, the speeds of rotation being 300, 600, 900, and 1,200 revolutions per minute respectively.

In all cases the observed rise of temperature is less



NOTE.—The Positions of Thermometers at different Layers are indicated on the Curves by black dots.

PLATE XI



NOTE.—The Positions of Thermometers at different Layers are indicated on the Curves by black dots.

when the armature carries a current of 30 amperes than when it is running light. The effect is not confined to the surface layers, and appears to increase slightly as the speed increases.

In Plates XV. and XVI. the 55-ampere curves in some cases fall slightly below those obtained when the armature was running light. This result was the subject of further experiments.

Increase of armature current decreases the concavity.

Summarising the results, it may be said *with reference to the indirectly fanned coil*—

(*a*) That there is a marked concavity in all curves showing the rise of temperature along the axis of the coil at any particular layer of the winding.

(*b*) That increased speed of rotation of the armature reduces this concavity under most conditions of armature load. (The reduction is not so marked at full load.)

(*c*) That if the armature current is unaltered, increased speed of rotation increases the temperature gradient to the surface of the coil through the depth of the winding.

(*d*) That increase of the armature current at a given speed of rotation does not result in so great an increase of temperature gradient to the surface of the coil as in the case of direct fanning. (At the higher speeds of rotation any such effect is entirely absent.)

A comparison of these results with those obtained in the case of the directly fanned coil (see p. 1197) will show that the magnitude of effects (*b*), (*c*), and (*d*) is much greater in the latter case. It may, therefore, be expected that the effect of the end surfaces will be less in the directly fanned coil than in the indirectly fanned coil, and the part played by the end surfaces in the dissipation of heat will now be considered.

In practice it is usual to neglect the end surfaces in estimating the area of radiating surface, except in the case of short magnets with deep windings. The experimental winding is 1·6 inches deep and 8·5 inches long, proportions

which would lead to the neglecting of the end surfaces. The heat developed in any element of the winding by the passage of a current is dissipated—

1. By conduction across the insulating material from layer to layer to the surface of the coil.

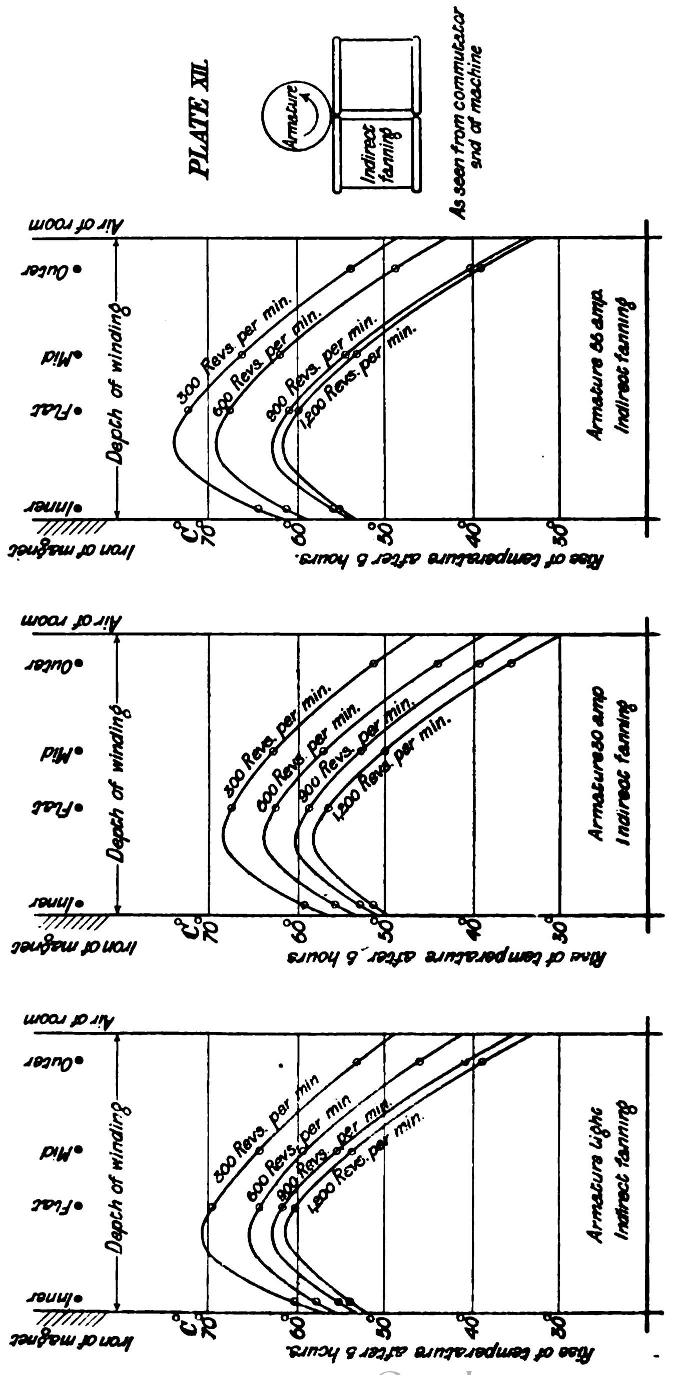
2. By conduction across the insulating material from turn to turn of any layer to the end surfaces.

3. By conduction in a spiral path along the wire itself.

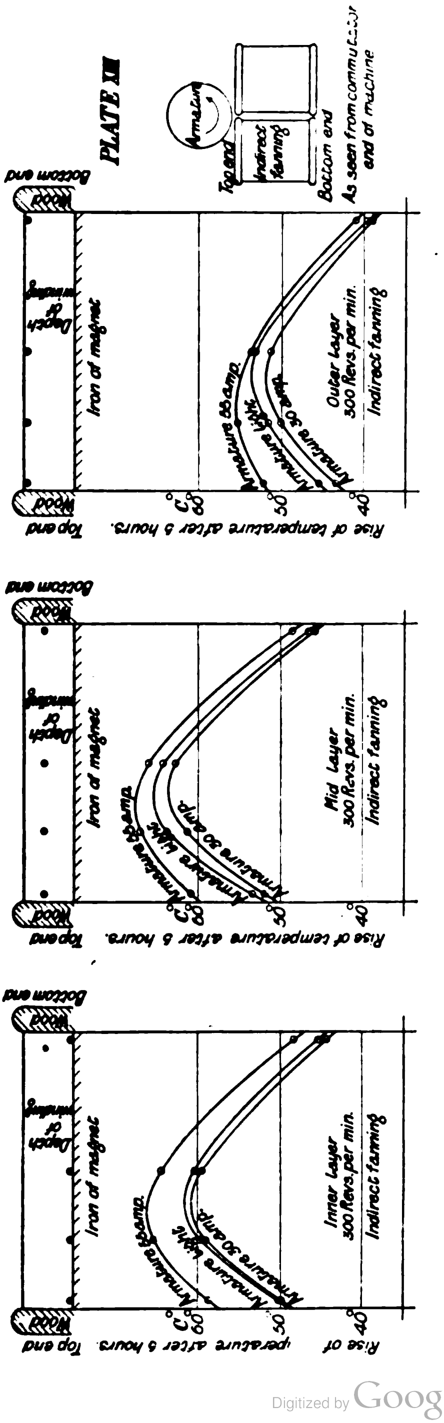
4. By raising the temperature of the element itself, this term disappearing when a steady state is reached.

With reference to the flow in a spiral path along the wire, consider a point in the winding about halfway along the axis at any layer. There is a temperature gradient towards one end of the coil, and therefore a flow of heat from the point considered towards that end along the wire. The temperature of the wire diminishes as the end is approached, and then begins to increase as the wire is wound back upon itself to form the next layer. The change from decreasing to increasing temperature must be a gradual one, or, in other words, the temperature gradient along the wire passes through a zero value at the end of the layer. The flow of heat along the wire is there zero. Hence the heat which commences to flow in a spiral path from a point situated at some distance from the end surface will be dissipated by lateral leakage across the insulation, either to the surface of the coil itself or to the end surface. The flow of heat in these two directions (1 and 2 above) will now be considered.

The temperature gradients to the surface of the coil and to the end surface, from a point halfway along the axis of the coil at the mid layer, have been measured from the curves for both direct and indirect fanning, and are tabulated on page 1188. The cases taken are those of light and full loads at the normal speed of the machine.



NOTE.—Curves refer to Points situated half-way along the Axis of the Field Coil. The Positions of Thermometers are indicated by black dots.



NOTE.—The Positions of Thermometers at different Layers are indicated on the Curves by black dots.

1,200 Revolutions per Minute.		Temperature Gradient to Surface of Coil. °C. per inch.	Temperature Gradient to End of Coil. °C. per inch.
Direct fanning	Armature light	22·1	0·73
	" 55 amp....	26·4	0·64
Indirect fanning	Armature light	24·9	2·33
	" 55 amp....	24·4	2·21

From these figures it follows that when the armature is running light, the temperature gradient to the surface of the coil from the point considered is about 30 times the gradient to the end surface when directly fanned, and about 10·7 times that gradient when indirectly fanned. The corresponding ratios when the armature is loaded are 41 and 11. The end surfaces are thus of greater importance in the latter than in the former case.

The difference in rise of temperature between thermometers equidistant from the top of the coil at the mid and outer layers is greater for the thermometers at the mid point of the axis than for those nearer the ends. Hence the temperature gradient to the surface of the coil is less at horizontal sections near the ends than at sections near the mid point of the axis. On the other hand, the temperature gradients to the end surfaces are greater from points near the ends than from points near the mid point of the axis. For this double reason, the end surfaces become of greater importance as they are approached from points some distance along the axis of the coil. By comparing the drop in temperature from the mid to the outer layer, as given by the thermometers at the top end of the coil, with the drop which exists between these layers halfway along the axis where the temperature gradient is known, some estimate can be made of the temperature gradient to the surface of the coil at a horizontal section near the end. Such an estimate was made in the cases just considered, and it was found that the temperature gradient to the surface of the coil from a point situated ¼ inch from the top end at the mid layer was about 4·7 times the temperature gradient to the end surface when running light, and about 7·0 times

that gradient when running at full load (55 amperes), the coil being directly fanned and the speed being 1,200 revolutions per minute. Corresponding figures for the case of the indirectly fanned coil were found to be 4·3 and 4·6. Such estimates are necessarily approximate, but the figures show that the end surfaces are much more comparable with the surface of the coil itself in the radiation of heat from parts of the coil near the ends than from parts near the mid point of the axis.

In order to obtain some idea of the effect of the end surfaces, the coil was removed from the machine and placed on supports, so as to raise it some distance from the floor. A current of 2½ amperes was passed through the coil, and the rises of temperature of the various thermometers observed. The ends of the coil were then covered with layers of felt, which did not, however, obstruct the free passage of air through the coil. The same current was then passed through the coil, and the rises of temperature observed. The differences of rise of temperature in the two cases are shown below. The increased rise of temperature when the ends were felted was most marked at the ends of the coil, as would be expected, and was greater at the inner than at the mid or outer layers.

	Rise of temperature, ends of coil felted, minus rise of temperature, ends of coil not felted. Coil standing in air off the machine. °C.		
	Top end.	Halfway along axis.	Bottom end.
Inner layer	6·2	3·6	6·3
Mid layer	4·9	2·6	4·7
Outer layer	3·7	1·9	3·1

The coil was then placed on the field magnet limb, the neighbouring field coil and armature being removed. Two similar experiments to the above were made to ascertain the effect of felting the ends when the coil had an iron core. The rises of temperature were again greater when the ends were felted, and were more marked at the ends of the coil than at points halfway along the axis. The differences in rise of temperature were, however, much smaller than when

1,200 Revolutions per Minute.		Temperature Gradient to Surface of Coil. °C. per inch.	Temperature Gradient to End of Coil. °C. per inch.
Direct fanning	Armature light	22·1	0·73
	„ 55 amp....	26·4	0·64
Indirect fanning	Armature light	24·9	2·33
	„ 55 amp....	24·4	2·21

From these figures it follows that when the armature is running light, the temperature gradient to the surface of the coil from the point considered is about 30 times the gradient to the end surface when directly fanned, and about 10·7 times that gradient when indirectly fanned. The corresponding ratios when the armature is loaded are 41 and 11. The end surfaces are thus of greater importance in the latter than in the former case.

The difference in rise of temperature between thermometers equidistant from the top of the coil at the mid and outer layers is greater for the thermometers at the mid point of the axis than for those nearer the ends. Hence the temperature gradient to the surface of the coil is less at horizontal sections near the ends than at sections near the mid point of the axis. On the other hand, the temperature gradients to the end surfaces are greater from points near the ends than from points near the mid point of the axis. For this double reason, the end surfaces become of greater importance as they are approached from points some distance along the axis of the coil. By comparing the drop in temperature from the mid to the outer layer, as given by the thermometers at the top end of the coil, with the drop which exists between these layers halfway along the axis where the temperature gradient is known, some estimate can be made of the temperature gradient to the surface of the coil at a horizontal section near the end. Such an estimate was made in the cases just considered, and it was found that the temperature gradient to the surface of the coil from a point situated $\frac{1}{4}$ inch from the top end at the mid layer was about 4·7 times the temperature gradient to the end surface when running light, and about 7·0 times

that gradient when running at full load (55 amperes), the coil being directly fanned and the speed being 1,200 revolutions per minute. Corresponding figures for the case of the indirectly fanned coil were found to be 4·3 and 4·6. Such estimates are necessarily approximate, but the figures show that the end surfaces are much more comparable with the surface of the coil itself in the radiation of heat from parts of the coil near the ends than from parts near the mid point of the axis.

In order to obtain some idea of the effect of the end surfaces, the coil was removed from the machine and placed on supports, so as to raise it some distance from the floor. A current of 2½ amperes was passed through the coil, and the rises of temperature of the various thermometers observed. The ends of the coil were then covered with layers of felt, which did not, however, obstruct the free passage of air through the coil. The same current was then passed through the coil, and the rises of temperature observed. The differences of rise of temperature in the two cases are shown below. The increased rise of temperature when the ends were felted was most marked at the ends of the coil, as would be expected, and was greater at the inner than at the mid or outer layers.

	Rise of temperature, ends of coil felted, minus rise of temperature, ends of coil not felted. Coil standing in air off the machine. °C.		
	Top end.	Halfway along axis.	Bottom end.
Inner layer	6·2	3·6	6·3
Mid layer	4·9	2·6	4·7
Outer layer	3·7	1·9	3·1

The coil was then placed on the field magnet limb, the neighbouring field coil and armature being removed. Two similar experiments to the above were made to ascertain the effect of felting the ends when the coil had an iron core. The rises of temperature were again greater when the ends were felted, and were more marked at the ends of the coil than at points halfway along the axis. The differences in rise of temperature were, however, much smaller than when

1,200 Revolutions per Minute.		Temperature Gradient to Surface of Coil. °C. per inch.	Temperature Gradient to End of Coil. °C. per inch.
Direct fanning	Armature light	22·1	0·73
	„ 55 amp....	26·4	0·64
Indirect fanning	Armature light	24·9	2·33
	„ 55 amp....	24·4	2·21

From these figures it follows that when the armature is running light, the temperature gradient to the surface of the coil from the point considered is about 30 times the gradient to the end surface when directly fanned, and about 10·7 times that gradient when indirectly fanned. The corresponding ratios when the armature is loaded are 41 and 11. The end surfaces are thus of greater importance in the latter than in the former case.

The difference in rise of temperature between thermometers equidistant from the top of the coil at the mid and outer layers is greater for the thermometers at the mid point of the axis than for those nearer the ends. Hence the temperature gradient to the surface of the coil is less at horizontal sections near the ends than at sections near the mid point of the axis. On the other hand, the temperature gradients to the end surfaces are greater from points near the ends than from points near the mid point of the axis. For this double reason, the end surfaces become of greater importance as they are approached from points some distance along the axis of the coil. By comparing the drop in temperature from the mid to the outer layer, as given by the thermometers at the top end of the coil, with the drop which exists between these layers halfway along the axis where the temperature gradient is known, some estimate can be made of the temperature gradient to the surface of the coil at a horizontal section near the end. Such an estimate was made in the cases just considered, and it was found that the temperature gradient to the surface of the coil from a point situated $\frac{1}{4}$ inch from the top end at the mid layer was about 4·7 times the temperature gradient to the end surface when running light, and about 7·0 times

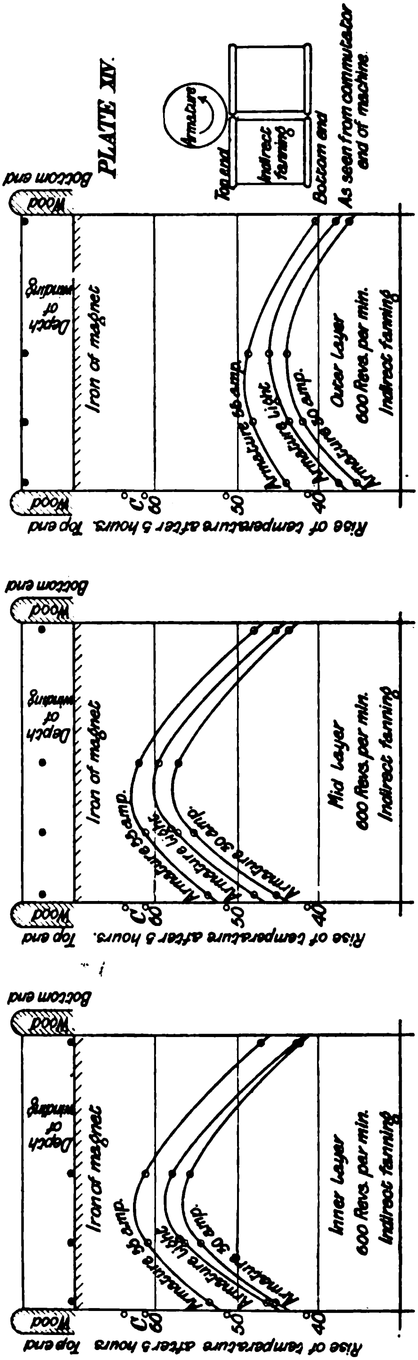
that gradient when running at full load (55 amperes), the coil being directly fanned and the speed being 1,200 revolutions per minute. Corresponding figures for the case of the indirectly fanned coil were found to be 4·3 and 4·6. Such estimates are necessarily approximate, but the figures show that the end surfaces are much more comparable with the surface of the coil itself in the radiation of heat from parts of the coil near the ends than from parts near the mid point of the axis.

In order to obtain some idea of the effect of the end surfaces, the coil was removed from the machine and placed on supports, so as to raise it some distance from the floor. A current of $2\frac{1}{2}$ amperes was passed through the coil, and the rises of temperature of the various thermometers observed. The ends of the coil were then covered with layers of felt, which did not, however, obstruct the free passage of air through the coil. The same current was then passed through the coil, and the rises of temperature observed. The differences of rise of temperature in the two cases are shown below. The increased rise of temperature when the ends were felted was most marked at the ends of the coil, as would be expected, and was greater at the inner than at the mid or outer layers.

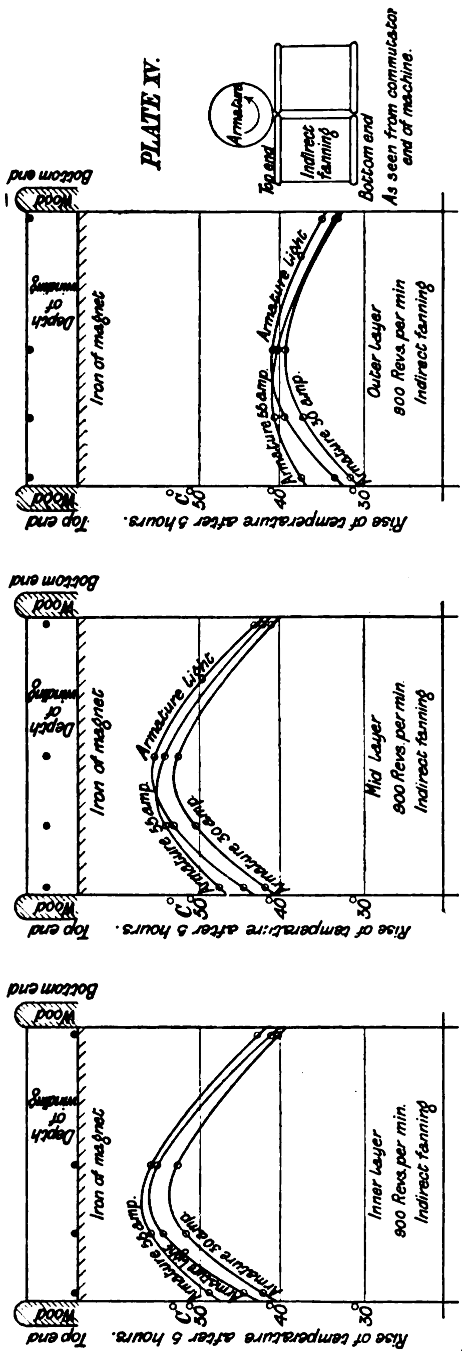
	Rise of temperature, ends of coil felted, minus rise of temperature, ends of coil not felted. Coil standing in air off the machine. °C.		
	Top end.	Halfway along axis.	Bottom end.
Inner layer	6·2	3·6	6·3
Mid layer	4·9	2·6	4·7
Outer layer	3·7	1·9	3·1

The coil was then placed on the field magnet limb, the neighbouring field coil and armature being removed. Two similar experiments to the above were made to ascertain the effect of felting the ends when the coil had an iron core. The rises of temperature were again greater when the ends were felted, and were more marked at the ends of the coil than at points halfway along the axis. The differences in rise of temperature were, however, much smaller than when

PLATE XIV.



NOTE.—The Positions of Thermometers at different Layers are indicated on the Curves by black dots.

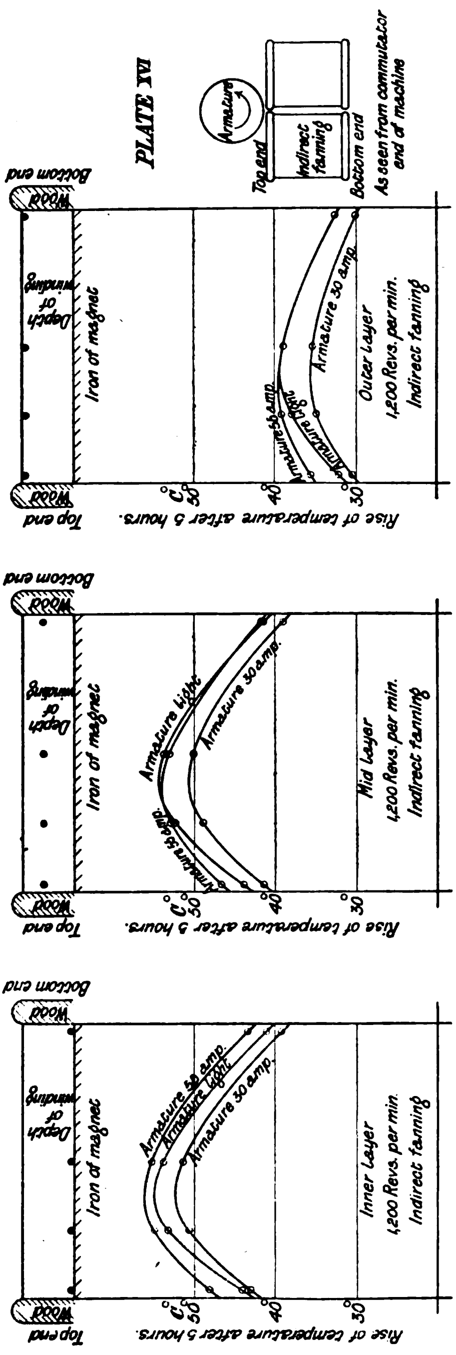


NOTE.—The Positions of Thermometers at different Layers are indicated on the Curves by black dots.

the coil had an air core, varying from 2° C. to 3° C. at the inner layer to from 1° C. to 2° C. at the outer layer. This is probably due to the fact that the rise of temperature was less when the coil had an iron core than when it was standing off the machine, the ends of the coil not being in either case felted. This difference of rise of temperature was as much as 7° C. at the inner layer, and 2° C. at the outer layer. The iron is thus more efficient in the removal of heat from the inner layers than the air convection currents, and it might be expected that the effect of felting the ends would be less in the case of an iron core than in the case of an air core.

In all these cases the concavity of the curves was very marked, yet the average increased rise of temperature produced by felting the ends when the coil had an iron core was not more than 3° C. Under normal working conditions the concavity would be less, and felting the ends would probably produce but little effect; but the wood ends of the bobbin form a fairly good thermal non-conductor, so that an additional layer of felt may matter but little. The curves seem to indicate that benefits would accrue to the coil if the ends were better heat conductors. Perforation of metal ends and insulating material, so arranged that the holes in the one do not come opposite the holes in the other, would improve the thermal conductivity of the ends; but the extent to which the conductivity could be improved by this or some other similar means would be governed by considerations of insulation resistance.

A probable cause of the concavity of the curves is the high temperature coefficient of the copper itself. Consider any layer of the winding initially at a uniform temperature. If an electric current is passed through it the rate of generation of heat will be the same in each element of the wire. After a few seconds the turns of the layer some little distance along the axis become slightly warmer than those nearer the ends. Consequently the rate of generation of heat in the elements now becomes unequal, being greater in the warmer than in the cooler elements. There is, therefore, a tendency to increase the inequality of temperature, which is itself the cause of unequal generation of heat. Such an effect is cumulative, and the curves become more and more concave as time goes on until a steady state is reached. If the wire



NOTE.—The Positions of Thermometers at different Layers are indicated on the Curves by black dots.

had a negligible or a lower temperature coefficient the concavity would probably be much less pronounced.

FURTHER EXPERIMENTS.

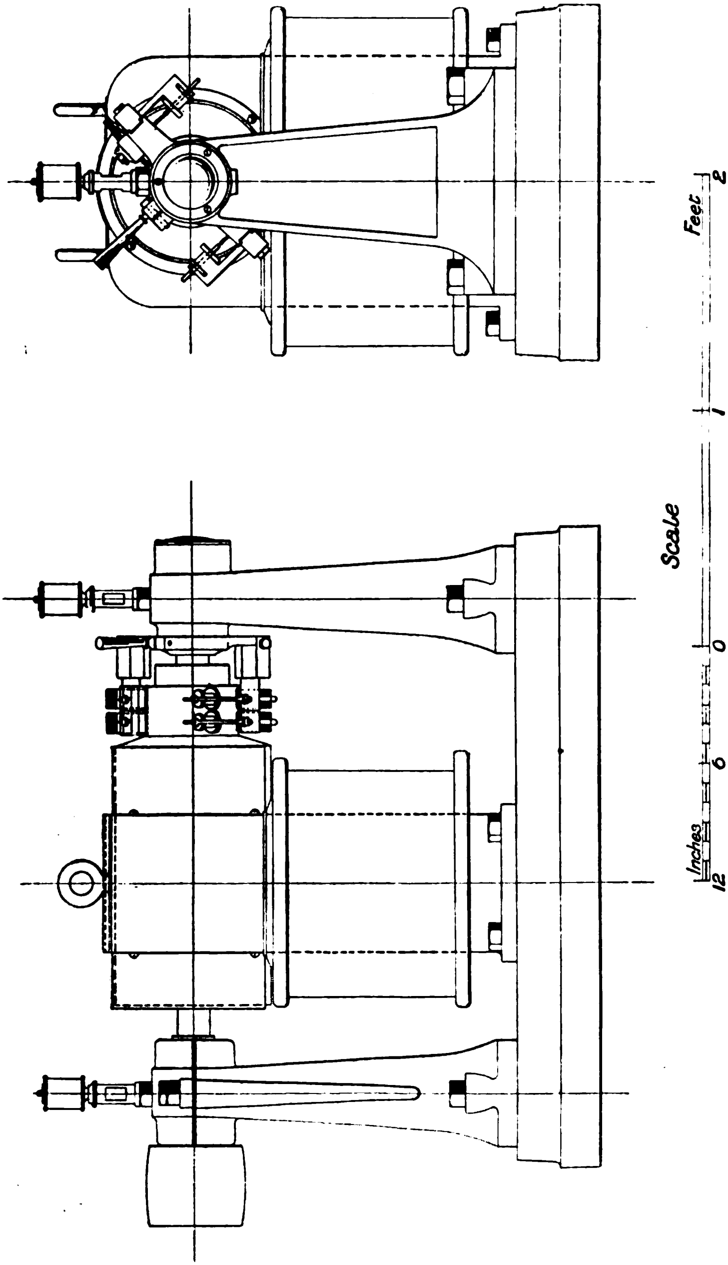
Further experiments were made to ascertain the cause of the unexpected crossing of certain curves previously noticed. (Plates I., III., VI., VII., XIII., XIV., XV. and XVI.)

The author thought that the effects might be attributable to the cooling action of upward convection currents of air, induced by the presence of a heated armature above the field coil. Experiments were made with a stationary armature carrying various currents, but the heating effects obtained in the coil were always greater than when the armature was cold.

Professor Ayrton suggested to the author that possibly the rotation of the armature gave directive action to convection currents. A lighted candle placed within a lamp glass from which access of air is excluded at the bottom, only continues to burn when some partial obstacle such as a metal strip is placed at the top of the glass. Heated air then ascends at one side, cold air to maintain the combustion descending at the other side of the glass. If there is an analogy between this simple experiment and the problem under consideration, then a speed of rotation quite insufficient to produce cooling effects attributable to fanning action should give such direction to convection currents as will result in smaller rises of temperature in the field coil when the armature is very slowly rotating, than when it is stationary, its temperature being the same in each case.

The experimental coil was placed on the indirectly fanned limb of the machine so as to be as free as possible from any cooling effects due to armature rotation only. The field coils were connected in parallel so as to produce a weak field, and a speed of 40 revolutions per minute was obtained without the use of a brake on the pulley, the armature current being 20 amperes. The armature temperature rose to 37·4° C. When the armature was stationary and carried 20 amperes its temperature rose to 35·5° C. The rises of temperature in the field coil were, however, from $2\frac{1}{2}$ to 3 per cent. *less* in the former than in the latter case.

PLATE XVII.



The armature was then run light at 40 revolutions per minute, attaining a temperature of 26·2° C. The rises of temperature in the field coil were $1\frac{1}{2}$ per cent. *greater* than when the armature carried a current of 20 amperes, rotated at the same speed, and attained a temperature of 37·4°. Other confirmatory experiments were made.

The results agree with those obtained at speeds at 300, 600, 900 and 1,200 revolutions per minute in the case of the indirectly fanned coil.

It may, therefore, be said that a heated slowly rotating armature produces a different effect from a heated stationary armature at practically the same temperature, and it further possesses the power of assisting or directing convection currents which is not possessed, or is possessed to a less extent, by a colder armature rotating at the same speed.

The observed effects, though small, are not ascribable to differences of initial temperature of the coil itself, which in every case are on the side of increasing rather than of decreasing them. Nor are they due to variations of room temperature. The rise of temperature of the room during an experiment was usually about 1·5° C., and never varied by more than 0·5° C. on any two days. A separate experiment, in which there was no current through the coil, showed that it followed the changes of room temperature very slowly.

In the case of the directly fanned coil, the crossing of the curves in Plates I. and III. is probably due to the cold convection current of air impinging on the bottom end of the coil. Such a convection current would have full scope for action, as the fanning action due to armature rotation is small at the bottom end of the coil at these speeds. The driving of the point of maximum temperature at the outer layer along the axis of the coil towards the bottom end may also tend to produce the crossing of the curves.

Directly Fanned Coil.

With reference to the smaller rise of temperature observed in the case of the directly fanned coil at speeds of 600 and 900 revolutions per minute, when the armature carried a current of 30 amperes, than when it was running light (Plates VI. and VII.), the author regrets that he cannot

put forward a definite explanation which would not appear to lead to the same result being produced at 1,200 revolutions per minute, when, as a matter of fact, this curious effect was not found to exist. The question is a complicated one, and the consideration of the following points may throw some light upon it.

When the armature was running light its surface temperature was taken by a mercury thermometer after each run, and it was found to increase with the speed. (See Fig. 8.) This is due to the fact that hysteresis and eddy-current losses are the chief causes of heating, and the latter

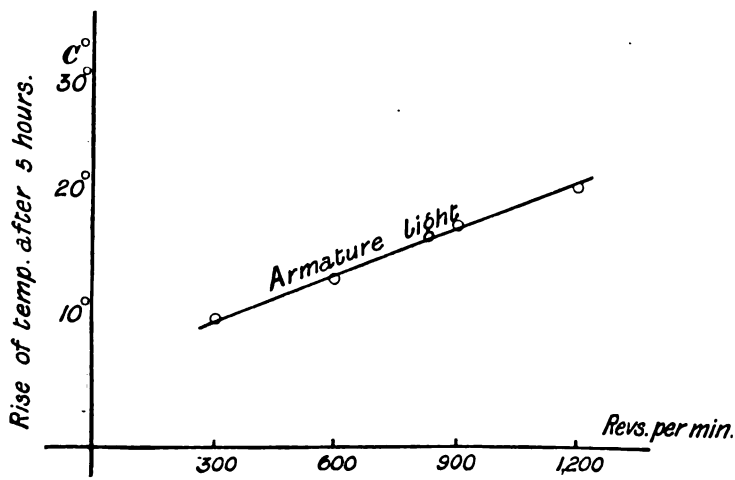


Fig. 8.

cause varies as the square of the speed. When the armature load is increased, C^2R losses come into prominence and the ordinates of Fig. 8 have to be increased. It was found that when the armature was loaded, its surface was unequally heated, and surface temperature readings were of no value. But it is clear from Fig. 8 that the armature temperature when the current is 30 amperes may be almost the same at all speeds, the ordinates having to be increased by larger amounts at the lower than at the higher speeds. The temperature of the air fanning the coil depends to some extent on the armature temperature and speed, the latter determining the time of contact of the air with the armature. Fig. 8 shows that the temperature of the air fanning the

coils may be nearly the same at all speeds when the armature runs light, because although the time of contact is less at the higher speeds the armature is hotter than at lower speeds. On the other hand, if the armature temperature when carrying 30 amperes is nearly independent of the speed, the temperature of the air fanning the coil would probably decrease as the speed increased. Such effects acting in conjunction with those described relative to convection currents may explain the results. Up to the present, the author is unable to put forward any other explanation.

CONCLUSION.

The results of the experiments may now be briefly summarised.

(*a*) Owing to the considerable temperature gradient towards the ends of the coil, more importance might with advantage be attached to making the end surfaces of as high thermal conductivity as insulation resistance requirements would permit.

(*b*) Owing to the important part played by the magnet cores in the removal of heat from the coil, an increase of the thermal conductivity of the materials interposed between the winding and the cores would be beneficial. Since the iron core is more efficient in the removal of heat from the coil than convection currents of air, it appears desirable that the bobbin should fit well on the magnet cores.

(*c*) Owing to the large difference of temperature between portions of the winding and the surface of the coil itself, especially about halfway up the coil, it might be advantageous to make the winding somewhat shallower about the mid point of the axis.

The surface of the coil itself is much more important than the end surfaces in the radiation of heat, but it is questionable whether the plan adopted in some recent machines of corrugating the surface with a view of increasing the cooling area is of much value, seeing that the area *normal* to the lines of flow of the heat is not thereby increased.

(*d*) In certain cases a considerable increase in the

current flowing through the armature is found to produce a sensible diminution in the temperature of the field magnet coils, although the current passing through them and the speed of rotation of the armature are kept unchanged.

In conclusion, the author desires to thank Professor Ayrton and the members of his staff for much kind assistance during the progress of the work. He is also indebted to Professor Hay, Royal Indian Engineering College, Cooper's Hill, for many useful suggestions both before and during the research.

THE APPLICATION OF ELECTRIC POWER TO MACHINE TOOLS.

By C. BASIL NIXON.

(Abstract of a Paper read before the Students' Section of the Institution of Electrical Engineers, on Wednesday, May 1st, 1901.)

During the last six months quite a number of papers have been read before this and other technical institutions dealing with some branch of the subject of which this paper treats. The majority of the authors have, however, devoted themselves to examining various systems of distribution and advancing figures as to the economy of electrical distribution over the older methods of power transmission by shafting or by isolated engines.

Speaking generally, I suppose every engineer is convinced that in the majority of cases electrical transmission is better than any other known form, and that it should be adopted whenever circumstances permit. I shall not, therefore, take up time with arguments more suited to a meeting of works managers, or foremen engineers, but propose rather, by the kind permission of Mr. H. A. Hoy, Chief Mechanical Engineer of the Lancashire and Yorkshire Railway Company, to give a detailed account of two of the above-mentioned Company's plants, and to supplement it with results of tests made to discover the power required to perform various operations.

Leaving aside the propulsion of trains, there are an infinite number of uses to which electrical energy can be put on any ordinary trunk railway, the principal of such being arc and incandescent lighting, railway carriage lighting, and the driving of machine tools, pumps, cranes, hoists, lifts, capstans, etc. For such purposes the Lancashire and Yorkshire Railway Company have ten separate power-stations, two of which (those at Newton Heath and at Oldham Road, Manchester) I propose describing. There is nothing remarkable either in the arrangement or size of either of these plants, but I venture to hope that some particulars will be of interest to those in charge of similar installations.

(1) NEWTON HEATH WORKS.

The Newton Heath Works have a total ground area of forty-one acres and a covered area of twelve acres, and are employed in the construction and repairs of the Company's carriage, waggon, lurry and parcel-cart stock, the timber for the make of which is received in logs and the usual trade scantlings.

These works have been in operation some twenty-five years. The introduction of electricity is of recent date and as yet only partial.

Generating Plant.—The first electrical machinery introduced consisted of a dynamo belted to the saw-mill shafting, and was used to light the mill and general offices as a precaution against fire. This was followed three years ago last autumn by two Willans engines with Mather and Platt continuous-current compound-wound dynamos of 65 kilowatts at 135 volts capacity. These sets were followed early last year by two others of the same capacity but of the Company's own design, made at their Horwich works.

The pressure of supply is at present 110 volts, but it is proposed to change this to 220 volts, three-wire system, new motors being wound for 220 volts, but the incandescent lighting remaining at 110 volts.

It is thought that 110 volts is more convenient where a large number of portable lamps are in use, the plug connectors and flexibles of which have to be handled by non-technical men.

Arc Lighting.—There are at present seventy-six arc lamps, mostly of the double carbon open type, together with a few enclosed lamps in positions difficult of access for purposes of trimming. The wires serving the outside lamps are bare on insulators.

Incandescent Lighting.—There is an equivalent of 1,850 lamps of 8 C.P. in use, 180 of these being portable lamps for the use of workmen in coaches. The method of connecting the portable lights is by adapters and extra lamp-holders on the fixed drop-light fittings.

When the drop is used exclusively for portable lamps the system works fairly well, but where it carries also a lamp-shade and is fixed higher than ordinarily the wear and tear is very heavy.

When carrying out work in this manner three-wire flexible should be used, and a third lead run so that the fixed lights and portables may be on different circuits. The portables are required by day as well as during lighting hours.

Motors.—The aggregate horse-power fixed or in progress is 277 B.H.P., which has been arranged so as to do away with all outlying steam plant, leaving only three large steam engines in use.

As soon as more steam is available it is proposed to put motors on all the heavy machines in the saw-mill, which are situated at the end of the shop opposite to the engine, and therefore in the worst possible position for shaft transmission, the more so because these machines consist of large saws and planes, which are at rest a great many more hours than they are in use.

The sizes of motors at present on the ground are 18 H.P., 7 H.P., 5 H.P., 1½ H.P., besides three or four small ones on fans, hoists, etc. They are of Manchester type, shunt, series, or compound wound according to the work to be done by them. The armatures are slot-wound and heavily banded.

The starting-switches are of very simple form, consisting of a teak board frame, 1 ft. 7 in. × 11½ in., on which are mounted a fuse block and switch ; the former placed on the negative wire covered by a metal box and glass lid, the latter provided with a short-circuit contact for the field coils and two intermediate contacts between off and on. The

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resistance coils are of high-resistance wire, mounted on porcelain bushes and connected together by brass bars. This form of starting resistance is cheap and gives little trouble; it is capable of permitting the starting of an 18-H.P. motor connected to its shafting without appreciably affecting the lights; the motors are started up immediately before work starting-time.

Output.—The percentage which the average current spread over the working hours of one week bears to the maximum observed current during the same period is found to vary from 16 to 25 per cent. It is thus low on account of running all night with a load of only eleven arc lamps.

The aggregate horse-power is 295, the maximum output being 76 per cent. of this; and the output of the plant, allowing one unit reserve, is 78 per cent., thus showing the plant to be fully loaded. The average output is, however, only 50 E.H.P., *being not more than 17 per cent. of the aggregate.* Dealing now with motors only, you will see by the chart that the average output is 61 H.P.; the reason why this appears higher than the total or combined light and power average is that the former is taken over the total running hours and the latter over the motor hours only, viz., sixty-three per week. Most of the motors run all day, so that there is not a very great difference between the various outputs.

The total output for the year is at present about 218,000 units.

(2) Oldham Road Goods Yard.

Plant.—This plant was installed to replace a system of capstans and hoists driven by shafting by four engines situated at an average distance of 80 feet from the boiler plant. The shafting consisted of some 700 yards of 2½ and 3½ inch section, and drove the capstans by mitre wheels; these shafts were often twisted off.

The present plant consists of three Lancashire boilers working at 160 lbs. per sq. in. pressure, supplying steam to three high-speed, continuous-current, direct-coupled, shunt-wound generating sets having an output of 65 kilowatts each at 130 volts pressure. These are supplemented by an E.P.S. accumulator of exceptional size, consisting of 64 cells of 41 plates each, capable of a discharge of 1,000 amperes for one hour.

Boosting.—Ordinarily the battery is connected direct to the bus-bars and gradually loses current throughout the day; once a day it is put in series with the booster and recharged. The booster motor has a few turns of wire on its field-winding carrying the main current, which reduces its potential at times of maximum output. A few of the end cells have been arranged as regulators.

Output.—There is a great difference in this case between the aggregate power of the motors and the actual output. Table I. shows that the capacity of the generators, when one unit is held in reserve, is only 28 per cent. of the aggregate power, and that the maximum recorded

output is 30·5 per cent., the average output being only 10·2 per cent. of the aggregate, thus showing the advantage of using a battery of accumulators.

The output for one year is about 338,000 units, and the load factor is about 40 per cent.

Lighting.—Considering that the premises to be lighted are principally warehouses and loading stages, no special provision had been made for lighting purposes. Separate cables, however, are run to a main switchboard.

The lighting is by means of open and enclosed arcs and incandescent lamps, the interior wiring being on the distribution system, the wires being run in simplex tubing.

Power.—This is supplied to 20 capstans, each capable of manipulating a load of 18 loaded waggons; the capstans each have their own motor and are actuated by foot plungers similar to those on the hydraulic capstans, the switch being controlled by an air dash-pot. Each capstan has a two-pole switch fitted in the chamber beneath it; this switch is provided for the attendant when inspecting and oiling the machine. On the main switchboard there are a two-pole switch and single-pole fuse for each capstan. It was thought that if the fuses were in the capstan chambers great inconvenience might result, and subsequent events have proved that the expense of a separate cable to each motor was more than justified. Each capstan has a fuse consisting of strands of copper wire.

Cables.—These are of concentric form with impregnated paper insulation, with lead sheathing laid in the races through which the shafts used to run.

(3) Power Required to Drive Various Machines, Hoists, Etc.

I was in doubt for some time whether to include in the table all results which I had reason to believe correct, or only those I had personally obtained; I finally decided to present my own results only, with the addition of two or three independent figures which confirm those I have obtained. Figures other than mine are marked *x*. The charts showing the current at various times have been taken by an Elliott recording ammeter provided with three shunts of 200, 500, and 2,000 amperes respectively. The instrument is fairly well damped, and I consider that the peaks, except those of starting the motors, are not exaggerated by reason of the momentum of the instrument; but there are doubtless slight errors owing to the friction of the pen on the paper—not sufficient, I hope, to detract from the value of the results.

Diagrams were shown illustrating an 18-H.P. motor coupled to a 36-inch saw and a 6-spindle boring mill: an 18-H.P. motor driving three saws 22-inch diameter, and cutting 11½ × 4¾ oak: a motor coupled to a 24-inch saw cutting 7½ × 2½ pine: and the working of a 10 cwt. direct-coupled hoist running at 80 feet per minute, driven by a compound-wound motor. Another diagram showed the power used by a roller planer surfacing all four sides of 9 × 3 deal at 80 feet

per minute. The work was clearly too much for the 18-H.P. motor, and as this is by no means the heaviest work passed through the machine it has been decided to put down a 40-H.P. motor. Another showed the working of a 7-H.P. motor driving a length of shafting; the vacuum pump driven by this shaft has its belt shifted from the fast to the loose pulley by an auxiliary cylinder, according as the pressure varies—this is the reason for the heavy peaks. I may add, however, that it has had no bad effects on the motor, which has now run ten months without any repair being found necessary.

A further diagram showed the remarkably low power consumed by a large warehouse of five stories containing 24 hoists of 15 to 20 cwt. capacity. One 18-H.P. shunt-motor drives the whole shafting, viz., 380 feet of 2 inch and 4 inch and six pair of bevel wheels. The loads are to a large extent lifted by the momentum of the moving shafts, and the heavy belt-driven pulleys used.

When I tell you that this warehouse used to be driven by a 4-inch underground shaft over 100 yards long you will readily understand that very considerable saving has been the result of the change.

Considering the regularity of the work and the part played by momentum, I doubt whether there would be any advantage in a separate motor for each hoist.

A description followed of a 15-ton waggon hoist worked by two shunt motors of 30 H.P. each, the lift being raised by shifting belts but lowered by brake only. Both in this case and in the following there are two cages balanced one against the other; when lifting or lowering a loaded waggon it is usual to lower or lift an empty one in the other cage, thus helping to balance the load. The second lift was worked by a 40-H.P. series motor. The power used for six complete journeys was for the shunt hoist 12·5 units and for the series 3 units. A lift which has some 12 tons put suddenly upon it requires different treatment to one which has the same load gradually loaded upon it.

The tables now produced give in No. I. the cost and output, in No. II. a list of the watts required for various tools: the column devoted to motors giving a figure representing the best size of motor for the work, the rating being such that the motor is capable of running for a prolonged period at its rated power, and being also capable of sustaining 50 per cent. overload for a few minutes.

My experience has taught me the great advantage of direct-coupled series or compound motors for hoists and cranes. A point I have not seen mentioned in this connection is that it is impossible to run a crane controlled by shifting belts at so fast a rate as a series motor crane because the sudden start causes the load to swing in a dangerous manner, when removing it from the machine or other confined position: with a series motor the gantry may be started slowly, but when the load is clear it may be carried down the shop at a speed as high as 350 feet per minute; it would be quite impossible *to start off* at this speed; the same applies, though to a less extent, in lifting.

In conclusion, I may say that I am hoping that others have come prepared to give their experience in this field in order that the discussion may be of some value by a comparison and checking of results.

For some interesting particulars of power for foundry tools, I would call your attention to the communicated discussion on Mr. Langdon's paper before the Institute of Mechanical Engineers at the Derby Meeting.

I must again express my indebtedness to Mr. Hoy for permission to make known the details I have here given, and to Messrs. Robinson for the use of the table showing the sizes of motors they would adopt to drive various wood-working machines.

TABLE I.

Particulars of Current Consumption at Newton Heath Works.

a. Theoretical Horse Power Motors ...	171	E.H.P.		
b. Lights	124	„		
c. Total	295	„		
d. Max. Recorded Output	224	„	—	76 per cent of *c.*
e. Average Output during 10 weeks ...	50	„	—	17 „ „
f. Total Capacity of Generating Plant ...	310	„	—	105 „ „
g. Capacity of Generators 1 Unit spare is	230	„	—	78 „ „
h. Theoretical Horse Power of Motors ...	171	E.H.P.	—	
i. Max. Recorded Output	93	„	—	54 per cent of *h.*
k. Average Output during 10 weeks ...	61	„	—	36 „ „
l. Output for Year	218,000	B.T.U.		

Particulars of Current at Oldham Road.

m. Theoretical Horse Power Motors ...	562	E.H.P.		
n. Lights	47	„		
o. Total	609	„		
p. Max. Recorded Output	185	„	—	30·5 per cent of *o.*
q. Capacity of Generating Plant	255	„	—	41 „ „
r. Capacity 1 Unit spare	170	„	—	28 „ „
s. Capacity of Battery for 1 Hour ...	150	„	—	
t. Average Recorded Output	62	„	—	10·2 „ „
u. Output for Year ... ... about	338,000	B.T.U.		

TABLE II.

Machine.	Work being done.	H.P. of Motor.	Watts taken.	
			Light.	Working.
1. Friction per lb. of shafting ...	Running in clean situations	...	1·5	...
2. Friction per lb. of shafting ...	Running in average situations	...	2·6	...
3. Friction per lb. of shafting ...	Running below floor	...	5·2	...
4. Friction per lb. of shafting ...	Average of seven separate shafts ...	...	3·1	...
5. Portable electric drill	Hole ⅞ in. × ⅞ in. in 2·5 min....	1	495	825
6. Forge fan ...	Fourteen fires, average consumption ...	10	...	5,800
7. " "... ...	Twenty-four fires average consumption ...	...	...	7,850x
8. Roller planer 7 in. × 14 in. ...	Planing four sides of 9 × 3 deal 80 ft. per min....	40	11,900	21,000
9. Roller planer 7 in. × 14 in. ...	Planing four sides of 6 × 3 oak 80 ft. per min....	...	5,950	28,800x
10. 48 in. saw ...	Ripping 18-in. teak 6 ft. 6 in. per min. ...	18	...	18,000x
11. 36 in. " ...	Ripping 9 in. oak ...	12	3,080	14,080
12. 28 in. " ...	Ripping 9½ in. oak ...	...	1,120	14,900x
13. Triple cross-cut saw	Three cuts 7 in. × 4½ in.	15	5,050	14,600
14. General saw, 18 in. diameter ...	Cutting 7½ in. × 2½ in. and similar work ...	4	1,100	4,108
15. Triple sandpaper machine ...	40 in. Invincible papering panels 30 in. ...	18	7,900	11,900
16. 6-spindle boring mill	Boring 2 in. hole in oak	5	3,080	3,080
17. 24 in. band saw ...	Cutting 14 in. green heart	6	880	4,850
18. 20 in. " " ...	Cutting 3 in. bay ...	4	330	1,320
19. Firewood chopping and bundling	7 tons chopped, 81 cwts. bundled ...	4	1,320	4,400
20. 12 in. planer ..	Planing one face of 3½ in. pitch pine ...	2	1,150	1,300
21. Double vertical planer	Working on bay—heavy work ...	3	1,760	1,760
22. Single vertical moulder ...	Working on bay—light work ...	1·5	660	900
23. Defiance sand-paper belt ...	Working on lurry-lurry spokes ...	2	1,200	1,210
24. Copying lathe ...	Lurry spokes oak ...	1·5	880	880
25. Single ended tenoner	Heavy type cut 2½ in. × 3⅜ in. oak ...	7	2,240	5,200x
26. Single ended tenoner	Light type cut 2½ in. × ⅝ in. bay... ...	3	1,100	1,870
27. Morticer	Chain type 3 in. × 2½ in. × ⅜ in. bay ...	2	330	1,430

TABLE II.—*Continued.*

Machine.	Work being done.	H.P. of Motor.	Watts taken. Light.	Watts taken. Working.
28. Fret Saw ...	Cutting 1 in. bay ...	½	330	330
29. Paint mixing ...	4 large, 4 small mixers, 1 Raveller, 1 putty M.	4	...	1,760
30. Robinson Grinder	Grinding Peas, 1 bag in 10 minutes. ...	4	...	2,200
31. Chopping Hay ...	6 bags in 10 minutes	7	...	6,250
32. Hair Comber ...	Laycock's	¾	350	350
33. Capstan	To pull 18 waggons 300 ft. per min. ...	20	880	27,500
34. Jiggers in Warehouse	24 hoists 15–20 cwt. each	15	5,000	8,800
35. Capstans (9) ...	Driven by underground shaft ...	30	6,250	37,500
36. Lifting Waggon	38 ft. per minute shunt motor	40	10,500	34,000
37. " " ...	38 ft. per minute series motor	40	...	27,500
38. Lift Waygood ...	10 cwt. 80 ft. per min.	5	...	5,300
39. 20-ton crane travel	114 ft. light, 90 ft. with 12·5 tons	8	5,720	8,800
40. 20-ton crane cross traverse ...	Lifting done by crabs, each having separate motors, light 7·3 ft.	1½	...	...
41. 20-ton crane lift	Loaded 12·5 tons 3·4 ft.	2 of 5	4,400	9,500
42. 5-ton crane ...	Single motor type sp. 175 ft. lift 7 ft. 6 in.	7	1,100	7,050
43. Stoker plant ...	For three Lancashire Boilers	4	...	2,500

TABLE III.

Supplied by Messrs. T. Robinson, Rochdale.

				Horse Power of Motor. A.	Horse Power of Motor. B.
Special Vertical Log Frame	Y5	72 in.	20 saws	35	40
Single Deal Frame	AO	24 "	4 "	12	12
Rack Saw Bench	P	72 "		40	40
Double Horizontal Saw Frame	8T	48 "	2 "	15	15
Radial Arm Roller Feed Saw Bench ...	DA	8 ft. ×	3 ft.	20	20
Large Four-side Planing Machine ...	S5	24 in.		15	18
High Speed Moulding Machine	GK	6 in. ×	2½ in.	12	15
Panel Planer...	Z3	30 "		5	7
Combined Hand and Power Feed Planer	BD	24 "		4	5
Double Tenoning Machine	FE			15	15
Large Power Morticing Machine... ...	PP			6	5
Armstrong's Dovetailing Machine ...	N.N	N. 36 in.		10	—

Column A gives the power of motor recommended by Messrs. Robinson.

Column B shows slight modifications which, as far as my experience goes, would, I believe, give better results.

CAPE TOWN LOCAL SECTION.

REPORT ON THE WORK OF THE SESSION.

The General Meeting which inaugurated the session was held on May 7, 1900, after a vacation of eight months occasioned through the members of the Local Section being largely occupied with extra work on account of the Boer War.

At the close of last session twenty-five members of the Institution of Electrical Engineers were resident in the Cape Peninsula ; this number has now increased to thirty-two : the Local Section has probably been instrumental in adding ten names to the roll of the parent Institution.

During the session eleven ordinary and two special meetings were held, the ordinary meetings being held in the Railway Electric Light Works, by kind permission of Mr. Denham ; thirteen papers read at the meetings of the parent Institution were discussed. The members were also favoured with a lecture and a practical demonstration by Messrs. H. D. Wilkinson and W. Gaye, of the Eastern Telegraph Company, on "The Working and Maintenance of Submarine Cables."

The meetings throughout have been of an extremely interesting nature, whilst they have, without doubt, proved profitable to the members present.

During the session, two members of the Local Section have received honours from Her Majesty—Sir David Gill, the Astronomer-Royal, having been made a K.C.B., and Mr. S. R. French, the Postmaster-General, a C.M.G. Several members have also been privileged to assist in various ways and in varying degrees the Naval and Military Authorities in the war still waging.

Financially the Local Section has made satisfactory progress ; the balance in hand at the commencement of the session was £1 1s. 9½d. ; it is now £3 2s. 5½d.

The election of Officers for the new session was held by ballot on February 4, 1901, when the following gentlemen were elected :—

Chairman	C. PROCTER BANHAM.
Vice-Chairman	JOHN DENHAM.
Member of Committee	F. PICKERING.
Secretary	W. J. HORNE (South African College, Cape Town).

SUPPLEMENTARY ACCOUNT OF THE WORK OF THE SECTION.

The Meetings are naturally of a less formal nature than can very well be permitted in England ; they are held in a large room attached to the Railway Electric Light Works, hence continuous and alternating current is always available for demonstrating purposes. The papers for discussion are circulated amongst the members prior to the meeting, at which they are "taken as read," and the discussion commences at

once. At the close, should time allow, the meeting is thrown open, and any member may introduce any other topic which may be of interest, or explain any problem which he has encountered in his work, and concerning which he would like the benefit of suggestions or advice. Members frequently also exhibit new apparatus or samples of cables, lamps, meters, etc. etc., that they may have received from home. Our endeavour is mutually to assist one another, and to foster a friendly feeling amongst members of the profession.

Members may introduce visitors, who may join in the discussions on the invitation of the Chair. Smoking is permitted, and coffee is served.

The Twenty-ninth Annual General Meeting of the Institution was held at the Society of Arts, John Street, Adelphi, on Thursday evening, May 30th, 1901 — Professor JOHN PERRY, F.R.S., President, in the Chair.

The minutes of the Ordinary General Meeting held on May 9th, 1901, were read and confirmed.

The names of new candidates for election into the Institution were announced.

The following transfers were announced as having been approved by the Council :—

From the class of Associate Members to that of Members—

George William Spencer Hawes. | Leonard Leslie Robinson.

From the class of Associates to that of Members—

John May.

From the class of Associates to that of Associate Members—

Gilbert Holt Green. | Standen Leonard Pearce.

From the class of Students to that of Associates—

Thomas Leslie James.

Messrs. J. Lister and H. L. Leach were appointed scrutineers of the ballot for the election of new members, and the ballot was proceeded with.

Donations to the *Building Fund* were announced as having been received since the last meeting from Messrs. Crawford, Evershed, and Colonel Stuart, and to the *Benevolent Fund* from Mr. Newstead and Mr. W. C. Smith, to whom the thanks of the meeting were duly accorded.

The PRESIDENT : I have now to call your attention to the very beautiful Address from the American Institute

of Electrical Engineers which has been sent over to us, and which has been already shown at the conversazione in America. I have also to announce the presentation of an Album giving some exceedingly interesting and some humorous photographs of our Swiss visit, and I ask you to give your thanks to the donors.

Agreed to.

ANNUAL REPORT.

The SECRETARY read the Annual Report of the Council:—

REPORT OF THE COUNCIL TO THE ANNUAL GENERAL MEETING, MAY 30TH, 1901.

DEATH OF HER MAJESTY THE QUEEN.

The death of Her Majesty Queen Victoria occurred during the Session now closing, and the Institution shared to the full in the public grief at the irreparable loss which the Nation had sustained.

The meeting of January 24th was abandoned, and a vote of condolence and of loyalty to His Majesty King Edward, passed by the Council, and endorsed at the subsequent Ordinary General Meeting of the Institution, was transmitted to His Majesty through the office of the Home Secretary. Similar resolutions from the Local Sections in Calcutta, Cape Town, Dublin, Glasgow, Manchester, and Newcastle were forwarded simultaneously.

LOCAL SECTIONS.

The Council has to report the creation of new Local Sections in Birmingham and Calcutta. It congratulates the Institution on the good work that has been done by the various Local Sections during the past year, and feels that the first Session during which they have been in full operation has given ample proof of the need for the movement inaugurated in 1898. The Council shares in the deep sorrow felt by the Dublin Local Section in the grievous loss that it, and the whole Institution, has suffered by the death of the first Chairman of the Section, Professor G. F. Fitzgerald.

ELECTIONS AND TRANSFERS.

It is with pleasure that the Council reports that it has elected as Honorary Member duriug the twelvemonth now ending, Mons. E. Mascart, to whom, as President of the International Electrical Congress of Paris in 1900 and as Vice-President of this Institution, the Council attributes much of the success of the Institution visit to the Paris Exhibition.

The increase in the membership of the Society continues satisfactory.

During the past twelve months there have been elected 21 Members, 89 Associate Members, 5 Foreign Members, 140 Associates, and 173 Students, making a total of 428. 54 Candidates have also been approved for ballot to-night.[1]

10 Associate Members, and 19 Associates of the Institution, and 1 Member of the late Northern Society of Electrical Engineers, have been transferred to the class of Members, whilst 46 Associates of the Institution and 4 Members of the Northern Society have been transferred to the class of Associate Members, and 46 Students of the Institution and 1 Member of the Northern Society to the class of Associates.

Deaths and Resignations.

It is with deep regret that the Council records the loss to the Institution by death of 1 *Honorary Member*, Adolphe Cochery; 1 *Chairman of a Local Section* (*Member*), Professor G. F. Fitzgerald; 2 *Local Hon. Secretaries*, Colonel P. B. Walker (*Member*), Don Señor F. de Vazquez (*Foreign Member*); 6 *Members*, E. H. Bold, C. E. Grove, C. Hall, W. Johnson, E. W. Parsoné, E. Willmore; 4 *Associate Members*, M. C. Dent, W. M. Oliver, H. Reason, H. K. Tavaria; 7 *Associates*, H. H. Eley, H. H. Fawckner, S. Hearne, W. O. Ross, E. C. Short, G. Smibert, F. C. H. White; and 2 *Students*, E. J. Morrah and C. Stewart.

Two Members, 1 Associate Member, 3 Foreign Members, 13 Associates, and 12 Students have resigned since the date of the last Report.

Papers.

In addition to the President's Inaugural Address, the following papers read at Ordinary General Meetings will have been published in this year's Journal :—

Date.	Title.	Author.
1900.		
Nov. 22.—	"Telegraphs and Telephones at the Paris Exhibition"	J. Gavey, Member.
„ 29.—	"Supersession of the Steam by the Electric Locomotive"	W. E. Langdon, Member.
Dec. 13.—	"On Rapid Variations of the Current through the Direct Current Arc"	W. Duddell, Associate-Member.
„ 20.—	"The Electrical Engineers' R.E. in South Africa"	Lt.-Col. R. E. Crompton, Past-President.
1901.		
Jan. 10.—	"The Use of Aluminium as an Electrical Conductor, with New Observations upon the Durability of Aluminium and other Metals under Atmospheric Exposure"	J. B. C. Kershaw.
„ —	"Capacity in Alternate Current Working" ..	W. M. Mordey, Member.

[1] As these Candidates were all duly elected, the numbers representing additions to the register since the Annual General Meeting in 1900 were, at the end of the meeting, as follows :—Honorary Member, 1; Members, 28; Associate Members, 100; Associates, 164; Students, 185; and Foreign Members, 5.

Date.	Title.	Author.
Feb. 21.—	"The Power Bills of 1900: Before and After"	W. L. Madgen, Member.
Mar. 7.—	"Insulation on Cables"	M. O'Gorman, Member.
„ 14.—	"Some Notes on Polyphase Substation Machinery"	A. C. Eborall, Member.
„ 28.—	"Some Notes on the Electrical Transmission of Power in Coal Mines"	H. W. Ravenshaw.
„ —	"Electrical Miners' Safety Lamps"	S. F. Walker, Member.
April 18.—	"On Test-Room Methods of Alternate-Current Measurement"	A. Campbell, Associate-Member.
„ —	"Note on the Use of the Differential Galvanometer"	C. W. S. Crawley, Member.
May 2.—	"An Instrument for Measuring the Permeability of Iron and Steel"	C.G. Lamb, Assoc.-Member. M. Walker, Associate.
„ 2.—	"A Watt-Hour Meter"	F. Holden, Member.
„ 9.—	"Storage Batteries in Electric Power-Stations controlled by Reversible Boosters"	J. S. Highfield, Member.

And the following papers selected from those read at the meetings of Local Sections have, up to the present, been accepted for publication :—

Date.	Section.	Title.	Author.
1900.			
June 14.—	Dublin.	"Dublin Corporation Electricity Supply Scheme"	R. Hammond, Member.
Nov. 14.—	Glasgow.	"Electricity Supply"	W. A. Chamen, Member.
„ 27.—	Manchester.	"Relative Advantages of Direct Current and Three-phase Distribution for small Installations"	H. A. Earle, Member.
1901.			
Jan. 14.—	Newcastle.	"Electrically Driven Machine Tools and their Advantages for use in Engineering Workshops"	G. Ralph, Associate-Member.
Feb. 12.—	Manchester.	"On the Training of Electrical Engineers"	Dr. J. T. Nicolson.
„ 13—	Glasgow.	"A Method of Compensating Voltmeters for Voltage Drop in Long Feeders"	M. B. Field, Member.
„ 26.—	Manchester.	"On the Use of Storage Batteries in Connection with Electric Tramways"	G. A. Grindle, Member.
„ 27.—	Birmingham.	"Inaugural Address of the Chairman"	Dr. O. Lodge, Member.
Mar. 12.—	Manchester.	"The Application of Steam Power to the Generation of Electrical Energy"	J. S. Raworth, Member.
„ —	Calcutta.	Inaugural Address of the Chairman	F. G. Maclean, Member.
„ 27.—	Birmingham.	"Polyphase Equipment of Factories"	W. Wyld, Associate-Member.
„ 29.—	Calcutta.	"The Insulation of Conductors of Electricity in India"	K. A. Scott-Moncrieff, Member.

The good attendance at Meetings referred to in the last Report has been maintained during the present Session, and the discussions on the

various papers read have been both valuable and interesting. The Institution again owes its thanks to the Institutions of Civil and Mechanical Engineers and to the Society of Arts for their generous permission to use their rooms for meetings.

Publications of the Institution.

The current year will mark the completion of the Thirtieth Volume of the publication of the Institution Journal. The General Index to Volumes 21 to 30 is, by order of the Council, in active preparation, and it is hoped that it will be ready for issue during the present year.

The wish having been expressed by many members that a uniform case for binding the Journal should be prepared, the Council has approved a pattern case in special waterproof cloth to be supplied at a small charge to those members who wish to have them.

The value and importance of *Science Abstracts* is now becoming more widely recognised, and the publication is, it is hoped, increasing in usefulness. The number of Abstracts appearing has increased from 2,000 in 1899 to 2,525 in 1900, and the Council desires to record its thanks to the joint publication Committee of the Physical Society and the Institution; to Mr. W. R. Cooper, the Editor; and to the Abstractors; who, by their combined efforts, have produced so full a record of current work in Electrical and General Engineering, and in Physical Science.

The publication of the following papers in the Journal as Original Communications has been ordered :—

"Note on Air Gap and Interpolar Induction"	F. W. CARTER, Associate.
"On the Absolute Values of Capacity Measurements" ..	J. ELTON YOUNG, Member.
"The Regulation of the Potentials to Earth of Direct Current Mains"	A. RUSSELL, Member.
"Note on Resonance with Alternating Currents"	A. RUSSELL, Member.
"Note on Duplexing Cables"	H. H. KINGSFORD, Member

Annual Premiums.

The Council has awarded the following premiums for papers and communications :—

The INSTITUTION PREMIUM, value £25,

to Mr. M. O'GORMAN, Member, for his paper entitled, "Insulation on Cables."

The "PARIS ELECTRICAL EXHIBITION PREMIUM," value £10,

to Mr. W. DUDDELL, Associate Member, for his paper entitled, "On Rapid Variations of the Current through the Direct-Current Arc."

THE "FAHIE PREMIUM," value £10,

to Mr. A. C. EBORALL, Member, for his paper entitled, "Some Notes on Polyphase Substation Machinery."

An EXTRA PREMIUM, value £10,

to Mr. J. S. HIGHFIELD, Member, for his paper entitled, "Storage Batteries in Electric Power Stations controlled by Reversible Boosters."

Four EXTRA PREMIUMS, value £5 each,

respectively to Mr. M. B. FIELD, Member, for his (Glasgow Local Section) paper entitled, "A Method of Compensating Voltmeters for Voltage Drop in Large Feeders"; to Mr. W. WYLD, Associate Member, for his (Birmingham Local Section) paper entitled, "Polyphase Equipment of Factories"; to Mr. G. RALPH, Associate Member, for his (Newcastle Local Section) paper entitled, "Electrically Driven Machine Tools and their Advantages for Use in Engineering Workshops"; and to Mr. F. HOLDEN, Member, for his paper entitled, "A Watt-Hour Meter."

The First "STUDENTS' PREMIUM," value £10,

to Mr. C. B. NIXON, Student, for his paper on "Application of Electrical Power to Machine Tools."

The Second "STUDENTS' PREMIUM," value £5,

to Mr. F. J. HISS, Jr. Student, for his paper on "Recent Work on Hertz Wave Phenomena and its Application to Wireless Telegraphy."

The Third "STUDENTS' PREMIUM," value £5,

to Mr. T. H. VIGOR, Student, for his paper on "Rotatory Converter Problems."

An extra "STUDENTS' PREMIUM," value £3,

to Mr. J. H. WEST, Student, for his paper on "Accumulators."

Papers, other than those of the Students' Section, which were not in type by April 30th were reserved for consideration in awarding premiums in 1902; but, on the other hand, certain papers which were received too late for consideration in 1900 have been taken into account in making the present award.

SALOMONS SCHOLARSHIP.

The Council has awarded two Salomons Scholarships, value £50 each, one to Mr. JOSEPH D. GRIFFIN, of the Central Technical College, and one to Mr. HERBERT ASHLIN SKELTON, of King's College.

DAVID HUGHES SCHOLARSHIP.

The sum of £2,000, referred to in the last Annual Report as having been bequeathed by the late Professor Hughes to found the "David Hughes Scholarship" in the Institution, has now been received from the Executors, and the Council has determined that, for the present, the manner of award shall be the same as that of the "Salomons Scholarship." They have selected Mr. CYRIL JOHN HOPKINS, of the Central

Technical College, as the David Hughes Scholar for the present year, the amount of the Scholarship being £50.

Students' Class.

In order to assist Students of the Institution to study the Electrical Exhibits in the Paris Exhibition, the Council appointed twenty Student-reporters, contributing to each £5 towards the expenses of his visit, each of these Students, on his return, submitting a report of the exhibits in a special branch of Electrical Engineering allotted to him by the Council. The following list contains the names of the Students appointed, together with the subjects on which they were respectively called upon to report.

Name.	Subject for Report.
Avila, J. F.	Arc and Glow Lamps and their Fittings.
Buckney, A.	Supply Meters.
Clough, F. H.	Switchboards and Switches.
Fisher, R.	Motors used in Mining.
Hurst, A. J. L.	Trolley Line Apparatus.
Irwin, J. T.	Alternating Current and Single-Phase Generators.
James, T, L.	Moving Platforms.
Jewson, F. K	Novel Telephone Apparatus.
Lester, L. R.	Non-integrating Meters.
Nettley, C. N.	Polyphase Generators.
Pearson, R. L.	Bi-polar Machines.
Solomon, M.	Electro-Chemistry (excluding Accumulators).
Stephenson, C. T.	Direct-current Multi-polar Generators.
Thomson, H. J.	Electro-Metallurgy.
Toppin, W. A.	Indoor Wiring.
Tracey, A. I.	Cables.
Tunbridge, S. A.	Laboratory Instruments.
Turnbull, G. E.	Indoor Electrical Fittings.
West, J. H.	Accumulators.
Whitaker, F. P.	Electrical Signalling (of all kinds).

The accounts submitted by the Students have for the most part been very favourably reported upon, and several of them have been read and discussed at meetings of the Students' Section. Thirteen meetings of the Section have been held during the Session, at which Students' reports and other papers were discussed. The Council desires to express its thanks to the members of the Institution who have been good enough to preside on these several occasions.

Visits to the following places were, at the request of the Students' Committee, arranged for the Students by your Secretary during the year, and the Council wishes again to record its thanks to those firms and gentlemen who so kindly gave facilities to the Students to visit their works :—

The Bankside Station of the City of London Electric Lighting Company, Limited.

The Davies Street Station of the Westminster Electric Supply Corporation, Limited.

The Manchester Square Station of the Metropolitan Electric Supply Company, Limited.
The Willesden Station of the Metropolitan Electric Supply Company, Limited.
The Board of Trade Laboratory.
The Central London Railway.
The London United Tramways, Limited.
The Waterloo and City Railway.
The Works of Messrs. Easton, Anderson, and Goolden, Limited.
" " the Electric Welding Company, Limited.
" " Messrs. Elliott Brothers.
" " India-Rubber, Gutta-Percha and Telegraph Works Company, Limited.
" " Messrs. Siemens Brothers and Company, Limited.
" " the Thames Iron Works Shipbuilding and Engineering Company, Limited.

In addition to the above, the Council sanctioned a proposal of the Students' Committee to arrange a visit to the Manchester District during the Easter recess. Thirty-two Students took part in this visit, which lasted four days, and the following works and installations were visited :—

The Cunard Steam Ship Company's R.M.S. *Lucania*.
Messrs. S. Z. de Ferranti, Limited.
The General Electric Company, Limited.
Messrs. W. T. Glover & Co., Limited.
Messrs. Hick, Hargreaves & Co., Limited.
Lancashire & Yorkshire Railway Company's Carriage Works.
The Liverpool Overhead Railway.
The Liverpool Tramways.
Manchester Corporation Electricity Department, Dickinson Street Station.
Messrs. Mather & Platt, Limited.
The Pumpfields Generating Station, Liverpool.
The Tudor Accumulator Company, Limited.

The Council would include these firms in the list of those to whom their thanks are due. They congratulate, also, Mr. L. R. Lester, the Honorary Secretary of the Students' Section, and the Committee of that Section, on the success of the visit.

Sectional Committees.

Having regard to the great increase in the number of members, and in the applications of electricity in Engineering and the Arts, and with the view of increasing the interest of the whole membership in the work of the Institution, the Council has created four Sectional Committees, each consisting of one or two members of the Council, with a number of representatives of the special interest represented, chosen

from members outside the Council. The number of members appointed by the Council was originally small, but the Committees were given power to add to their number with the instruction that the added members should be, for the most part, drawn from the general body of members of the Institution. The Committees were appointed to represent the following interests:—(1) Traction, Light, and Power Distribution: (2) Telegraphs and Telephones; (3) Manufacturing; (4) Electro-Chemistry and Electro-Metallurgy.

The Council hopes that if they will report on the relations between the Institution and their respective branches of electrical engineering, and on the special conditions or requirements for the time being of those branches, and if they are able to find a number of suitable representative papers each in its own section, for reading at meetings of the Institution, in addition to papers submitted in the ordinary way, the Committees may prove very helpful not only to the Institution, but to the industry.

Annual Dinner.

The Annual Dinner was held on December 3rd, in the Grand Hall of the Hotel Cecil, and the attendance was larger than at any previous Dinner of the Institution.

Annual Conversazione.

The Annual Conversazione was again held, by kind permission of the Trustees of the British Museum, in the Museum of Natural History, on June 26th. The band of the Royal Engineers performed on the occasion, and the attendance of members and guests was practically the same as in the preceding year.

Reception of the Active Service Contingent of the Electrical Engineers (R. E.) V.

In December, Colonel Crompton, with Captain Lloyd and the Contingent of the Electrical Engineers (R. E.) Volunteers who had offered their services in the South African campaign, returned to England after nine months of active duty. The Council felt that the Institution would wish to show their appreciation of the great services which the Contingent, representing the Electrical Engineers of the United Kingdom had rendered their Country at the time of need. It therefore arranged for a Reception of the Contingent at the Covent Garden Opera House, which was most kindly lent to the Institution for the occasion by Messrs. Frank Rendle and Neil Forsyth. A guard of honour commanded by Major Erskine was supplied from the members of the Corps who had remained at home. The Opera House was well filled, and the men received an enthusiastic welcome. Subsequently a sealed copy of the President's Address on this occasion was presented to each member of the Contingent. The Council takes this opportunity of congratulating Colonel Crompton and Major Erskine on the valuable work done by the Corps.

Annual Accounts and Financial Position.

The Council has again to congratulate the Institution on its financial position, for, notwithstanding the several heavy items of expenditure, there was a surplus of receipts over expenditure at the end of the year amounting to £1,549.

The sum of £128 9s. 4d. was invested on account of Life Compositions, leaving on December 31st a balance of £32, which has since been invested.

The estimated realisable amount of subscriptions outstanding on the 31st of December, 1900, was £400, and none of this is taken into account in the balance-sheet now presented; more than £170 of this has since been received.

Building Fund.

This Fund shows steady progress, having risen from £7,044 to £8,421 during the year 1900. Of this, £426 was contributed to the Fund by members, and £729 was transferred by the Council from the General Funds of the Institution.

Wilde Benevolent Fund.

The capital mentioned in the last Report as having been generously presented by Dr. Wilde for the endowment of a Wilde Benevolent Fund has been invested in Great Eastern Railway Company's Metropolitan 5 per cent. stock. No call has yet been made on the Fund, which is, at present, administered by the Council of the Institution.

Local Honorary Secretaries.

It was with the deepest regret that the Council received the notification of the death of two of your Local Honorary Secretaries, viz., Señor Don F. de P. Vasquez, who had represented Spain since 1895, and Colonel P. B. Walker, who had represented New South Wales since 1893. They have appointed Mr. Arthur Jackson, of Madrid, and Mr. J. Y. Nelson, of Sydney, to fill these offices respectively.

Owing to the increase of membership in the Argentine Republic, the Council, following precedent, decided to separate into two the previous joint Secretaryship for the Argentine and Uruguay. Mr. Oldham, who has, since 1886, acted as Local Honorary Secretary for the two Republics, retains the Local Honorary Secretaryship for Uruguay, and Mr. Ernest Danvers has been appointed Local Honorary Secretary and Treasurer for the Argentine.

Meeting of the Institution in Paris.

The Council learned with great satisfaction that the American Institute of Electrical Engineers purposed visiting Paris at the time of the International Electrical Congress, and was desirous of holding a Joint-Meeting with this Institution at that time. The Meeting was held, by kind permission of the Commissioner for the United States for the

Paris Exhibition, in the United States National Pavilion in the Exhibition on August 16th. The Meeting was attended by the President and many members of this Institution, and by the President and representatives of the American Institute. After a welcome, addressed to the two Societies by Mons. Mascart, a discussion was held on "The Relative Advantages of Alternating and Continuous-Current for the General Supply of Electricity, especially with regard to Interference with other interests." At the conclusion of the discussion, Mons. Hospitalier, Major-General Webber, Mr. Gavey, and Mr. Hering gave brief accounts of the Electrical Sections of the Exhibition. Most of the members present stayed during the time of the International Congress, and an afternoon Reception was held in the British Pavilion in the Exhibition.

The Council wishes to place on record its gratitude to His Majesty the King, and to the Members of the Royal Commission, for the permission to hold the Reception in a building so eminently suited to the purpose, and also for placing at the disposal of the Institution during the ten days of the visit a special office in the Commercial Information Bureau attached to the Pavilion.

Reception of the American Institute.

The visit of the President and many members of the American Institute of Electrical Engineers to Paris, gave the Council an opportunity, of which it availed itself with extreme pleasure, of receiving the members of the sister Institute in London prior to the Paris Meeting.

It was unfortunate that the time for this Reception was necessarily in the midst of the Summer Recess. Notwithstanding this, however, a large number of the members of the Institution were able to give a cordial welcome to their American colleagues. A Dinner at the Princes Restaurant, and a River Excursion from Henley were arranged for, and visits were paid to Works and Installations in and around London, the members of the party receiving the generous hospitality of Major-General Sir Thomas Fraser and the Royal Engineers Mess on the occasion of the visit to the Royal Dockyard and School of Military Engineering at Chatham. The opportunity for social intercourse with their American and French colleagues afforded by the visit of the American Institute to England, and that of the two Institutions to Paris, was much enjoyed by the members who were able to take part. The Council has every reason to hope that lasting benefits to the profession will result from such intercourse.

A handsome illuminated Address has been received from the American Institute of Electrical Engineers, conveying in cordial terms their thanks to the Institution for their reception in England, and for assistance in connection with their Paris Meeting.

Special Committees.

During the year the Council has appointed Special Committees, which are now in active operation. One of these is revising the Wiring

Rules of the Institution, and another is considering the possibility of drawing up a set of Model General Conditions for electrical contracts. In each of these cases the Council is receiving the welcome assistance of delegates from other bodies interested in the questions under discussion.

A Committee has also been appointed to determine whether it can recommend the Council to take any action, and, if so, to recommend the course to be followed, to assist the electrical industry in connection with the matters dealt with in Mr. Madgen's paper read before the Institution in February, entitled "The Electrical Power Bills of 1900: Before and After." The Council, recognising that there is a divergence of opinion on this subject, has authorised the Committee to receive evidence from representatives of different interests, and to print verbatim reports of its proceedings. It is hoped that in this way a full and fair statement of the difficulties, and of the views of those concerned, may be fairly presented.

Board of Trade Regulations.

At the request of the Council and by the consent of the Board of Trade, Lieut.-Col. Crompton and Mr. W. M. Mordey attended an inquiry of the Board of Trade in February, 1901, as delegates from the Council, to express the views of the Institution on the question of a proposed reduction from 8d. to 6d. of the maximum price per unit chargeable for electricity supply. They explained how the reduction of the maximum rate below 8d. per unit might make it commercially impossible for small towns to obtain electricity supply, and pointed out that experience indicated that the maximum was not usually maintained longer than was necessary to make the undertaking self-supporting. The result of the inquiry was that no absolute rule was to be made to reduce the maximum rate to 6d. per unit, if good cause could be shown for an 8d. or 7d. maximum in individual cases.

Employment Register.

The Council having at various times received applications, both from employers and candidates, for employment, has authorised the formation of an "Employment Register," which will be available for the use of those members (of all classes) who are not actually in employment, or who have given notice, or are under notice, to leave the appointments which they respectively hold. The forms in connection with this register are in preparation, and will, it is hoped, be ready by the beginning of the new Session.

The Library.

Report of the Secretary.

I have to report that the accessions to the Library during the seventeen months, from January 1, 1900, to the date of the Annual General Meeting, numbered 79; nearly all of these were kindly presented by the authors or publishers.

The supply of specifications of electrical patents and that of abridgments of specifications relating to electricity and magnetism are continued by the kindness of H.M. Commissioners of Patents, and the arrangement is still in force whereby the specifications of all electrical patents published during any week are placed on the Library table on the following Monday morning.

The periodicals or printed proceedings of other societies received regularly are, with some additions, the same as last year, as may be seen by the list appended hereto.

The number of visitors to the Library in the seventeen months from January 1, 1900, to the date of the Annual General Meeting, has been 785, of whom 53 were non-members.

WALTER G. McMILLAN, *Secretary.*

APPENDIX TO SECRETARY'S REPORT.

TRANSACTIONS, PROCEEDINGS, &c., RECEIVED BY THE INSTITUTION.

ENGLISH.

Asiatic Society of Bengal, Journal and Proceedings.
Cambridge Philosophical Society.
Engineering Association of New South Wales.
Greenwich Magnetical and Meteorological Observations.
Institute of Patent Agents, Transactions.
Institution of Civil Engineers, Proceedings.
Institution of Mechanical Engineers, Proceedings.
Iron and Steel Institute, Proceedings.
King's College Calendar.
Liverpool Engineering Society, Proceedings.
Municipal Electrical Association, Proceedings.
Northern Society of Electrical Engineers, Proceedings.
Physical Society, Proceedings.
Royal Dublin Society, Transactions and Proceedings.
Royal Engineers' Institute, Proceedings.
Royal Institution, Proceedings.
Royal Meteorological Society, Proceedings.
Royal Society, Proceedings.
Royal United Service Institution, Proceedings.
Society of Arts, Journal.
Society of Chemical Industry, Journal.
Society of Engineers, Proceedings.
South African Society of Electrical Engineers, Proceedings.
University College Calendar.

AMERICAN AND CANADIAN.

American Academy of Science and Arts, Proceedings.
American Institute of Electrical Engineers, Transactions.
American Philosophical Society, Proceedings.
Canadian Society of Civil Engineers, Transactions.
Engineers' Club of Philadelphia, Proceedings.
Franklin Institute, Journal.
John Hopkins University, Circulars.
Library Bulletin of Cornell University.
Nova Scotia Institute of Science, Proceedings.
Ordnance Department of the United States, Notes.
Technology Quarterly.
Western Society of Engineers, Journal.

BELGIAN.

Association des Ingénieurs Électriciens sortis de l'Institut Électro-Technique Montefiore, Bulletin.
Société Belge d'Électriciens, Bulletin.

DANISH.

Den Tekniske Forenings Tidsskrift.

FRENCH.

Académie des Sciences, Comptes Rendus Hebdomadaires des Séances.
Société Française de Physique, Séances.
Société des Ingénieurs Civils, Mémoires.
Société Internationale des Électriciens, Bulletin.
Société Scientifique Industrielle de Marseille, Bulletin.

GERMAN.

Verein zur Beförderung des Gewerbfleisses, Verhandlungen.

ITALIAN.

Associazione Elettrotecnica Italiana, Atti.

RUSSIA.

Section Moscovite de la Société Impériale Technique Russe.

LIST OF PERIODICALS RECEIVED BY THE INSTITUTION.

ENGLISH.

Cassier's Magazine.
Electrical Engineer.
Electrical Review.
Electrician.

Electricity.
Electro Chemist and Metallurgist.
Engineer.
Engineering.
Engineering Times.
English Mechanic and World of Science.
Feilden's Magazine.
Illustrated Official Journal, Patents.
Indian and Eastern Engineer.
Industries and Iron.
Invention.
Lightning.
Mechanical Engineer.
Nature.
Philosophical Magazine.

AMERICAN.

Electrical Review.
Electrical World and Electrical Engineer.
Electricity.
Journal of the Telegraph.
Physical Review.
Scientific American.
Street Railway Journal.
Western Electrician.

AUSTRIAN.

Zeitschrift für Elektrotechnik.

FRENCH.

Annales Télégraphiques.
L'Éclairage Électrique.
L'Électricien.
L'Industrie Électrique.
Journal de Physique.
Journal Télégraphique.
Le Mois Scientifique et Industriel.

GERMAN.

Annalen der Physik und Chemie.
Beiblätter zu den Annalen der Physik und Chemie.
Centralblatt für Accumulatoren und Elementenkunde.
Electrotechnischer Anzeiger.
Electrotechnische Zeitschrift.
Zeitschrift für Elektrochemie.
Zeitschrift für Instrumentenkunde.

ITALIAN.

Ellettricità.

Giornale del Genio Civile.

Il Nuovo Cemento.

SPANISH.

La Ingenieria.

The PRESIDENT: I have now to move, "That the Report of the Council, as just read, be received and adopted, and that it be printed in the Journal of the Proceedings of the Institution." I have almost nothing to add to this Report of the Council, but something which could not very well be put in the Report may be mentioned here. You will notice that no Member of Council received a premium for a paper. It is not that the papers by Members of Council were not worthy of premiums, but that the Council thought it well to pass a self-denying ordinance.

I think, gentlemen, you will agree with me that the papers and the discussions during the past session have really broken our record in the way of interest. That is my own feeling, and I attended all the meetings. I did not take part in the discussions, and feel quite capable of acting as an impartial judge. There is no doubt that the record is getting year by year a more difficult record to break. Another matter I should like to refer to is the tremendously important thing the Council has done in the appointment of the Sectional Committees. The more I think of what those Sectional Committees may do for the Institution, the more I feel that we have taken a very great step. It is a step which we can reverse, of course, although I hope we shall never have to do so.

Mr. HUGHMAN: I have much pleasure in seconding the adoption of this Report, and I have nothing to add except to say that I think it must be most gratifying to every member of the Institution to hear that we are getting richer and that our influence is steadily growing.

The resolution for the adoption of the Report was then put, and carried unanimously.

The PRESIDENT: I beg to move that the Statement of Accounts and Balance Sheet, of which copies were sent to the members with the notice convening the annual general meeting, be taken as read. (*Vide* pp. 1226–1235.)

The motion was then put, and agreed to.

The Institution of

STATEMENT OF RECEIPTS AND
ENDING 31st

Dr.

RECEIPTS.

		£	s.	d.
To Annual Subscriptions		5,126	8	0
„ Entrance Fees		596	17	0
„ Cash Balance paid by Northern Society of Electrical Engineers		184	12	7
„ Advertisements in the Journal		72	0	0
„ Publishing Fund		1	1	0
„ Dividends on Investments, viz.—				
Life Compositions	£153 15 10			
General Fund...	113 11 8			
		267	7	6
„ Interest on Cash on deposit		17	2	1
		£6,265	8	2

Electrical Engineers.

EXPENDITURE FOR THE YEAR DECEMBER, 1900.

Cr.

EXPENDITURE.

		£	s.	d.
By Salaries		891	13	6
„ Retiring Allowance...		300	0	0
„ Accountants' Fees, 1899	£10 10 0			
„ „ „ 1900	15 15 0			
		26	5	0
„ Shorthand Reporter		61	19	0
„ Attendance, Refreshments, Advance-proofs of Papers, and Petty Expenses connected with Evening Meetings		149	16	1
„ Printing, Illustrating, and Advertising Journal	£636 1 9			
Less Copies taken into Stock	62 10 0			
		573	11	9
„ General Printing and Stationery...		240	4	10
„ Insurance		9	15	0
„ Office Rent, Electric Light, and Firing		330	14	2
„ General Office Expenses, viz. :—				
Sundries	£85 17 3			
Diploma Cases	5 1 0			
Hon. Solicitors' Out-of-pocket Expenses to date	5 5 0			
Repairs to Typewriter	1 5 8			
Memorial Wreath for the late Lord Armstrong	1 11 0			
Postage of Journals, Notices of Meetings, &c.	447 0 2			
		546	0	1
„ Petty Expenses of Local Honorary Secretaries		3	14	5
„ Bank Charges		2	18	3
„ Conversazione Expenses (irrespective of Printing and Postage)		230	15	3
„ Premiums (1899–1900)	£85 15 11			
„ Grants to Student-reporters for Paris Exhibition	100 0 0			
		185	15	11
„ Expenses relating to the Paris Meeting...		128	9	11
„ „ „ „ Reception of the Active-Service Contingent of the E.E. Volunteers...		203	5	10
„ Contribution to "Science Abstracts"		730	0	0
„ Expenses connected with Local Sections		101	2	10
		4,716	1	10
„ Balance carried to General Fund, being excess of Receipts over Expenditure		1,549	6	4
		£6,265	8	2

LIFE COMPOSI-

Dr.

	£	s.	d
To Amount (as per last Account)	5,084	0	0
„ Life Compositions since received	116	0	0
	£5,200	0	0

TIONS ACCOUNT.

Cr.

					£	s.	d.
By Investments (as per last Account)—							
£400 0 0 New South Wales 4 % Bonds ...	£414	15	0				
318 0 0 Cape of Good Hope 4 % Consolidated Stock	306	0	0				
1,679 19 5 India 3½ % Stock	1,776	5	0				
120 0 0 South-Eastern Railway 5 % Debenture Stock	204	16	6				
355 5 10 Canada 3 % Stock	352	13	6				
289 17 4 Midland Railway 2½ % Consolidated Perpetual Preference Stock	274	11	10				
6 0 0 East India Railway Class "C" Annuity	185	1	9				
87 0 0 Great Eastern Railway 4 % Consolidated Preference Stock ...	130	15	2				
175 0 0 Great Eastern Railway 4 % Debenture Stock	251	5	5				
4 13 6 Great Indian Peninsula Railway "B" Annuity[1]	120	1	6				
143 0 0 Southwark and Vauxhall Water Co. 4 % Debenture Stock ...	207	17	9				
520 0 0 Staines Reservoirs 3 % Guaranteed Debenture Stock	539	2	3				
200 0 0 Glasgow and South-Western Railway 4 % Preference Stock (1894)	276	5	0				
					5,039	10	8
Investments Purchased since last Account—							
£29 0 0 Madras Railway 5 % Capital Stock	44	9	4				
57 0 0 South Indian Railway 4½ % Debenture Stock	84	0	0				
					128	9	4
					£5,168	0	0
" Balance uninvested at this date carried to Balance Sheet					32	0	0
					£5,200	0	0

[1] £70 5 % Capital Stock Converted.

"BUILDING FUND"

Dr.

		£ s. d.
To Amount (as per last Account)—		
" Investments	£6,852 8 9	
" Dividends uninvested	191 17 2	
		7,044 5 11
" Dividends received during 1900		199 2 2
" Subscriptions received during 1900		426 8 6
" Surplus from Vellum Diplomas to Dec., 1900		22 2 8
" Amount transferred from General Fund in 1900		729 11 10
		£8,421 11 1

Cr.

				£ s. d.
By Investments (as per last Account)—				
£450 0 0	Canada 4 % Reduced Stock ...	£504 0 0		
524 13 0	Canada 3 % Stock	553 10 1		
181 0 0	Great Western Railway 4½ % Debenture Stock	324 17 8		
418 0 0	South-Eastern Railway 3½ % Preference Stock	555 18 9		
370 0 0	London and South-Western Railway Preferred Ordinary Stock ...	510 12 0		
520 0 0	London and South-Western Railway 4 % Consolidated Preference Stock	821 12 0		
190 16 8	India 3½ % Stock	229 9 6		
387 0 0	Great Eastern Railway 4 % Consolidated Preference Stock	575 17 8		
529 12 0	Midland Railway 2½ % Consolidated Perpetual Preference Stock ...	500 0 0		
23 7 5	Great Indian Peninsula Railway "B" Annuity[1]	600 2 6		
80 0 0	London and South-Western Railway 3½ % Preference Stock	99 18 3		
504 0 0	Staines Reservoirs 3 % Guaranteed Debenture Stock	528 5 0		
670 0 0	Glasgow and South Western Railway 4 % Preference Stock (1894) ...	925 11 9		
75 0 0	Great Eastern Railway 4 % Debenture Stock	107 13 7		
15 0 0	South-Eastern Railway 3 % Preference Stock (1899)	15 0 0		
				£6,852 8 9
„ Investments (purchased since last Account)—				
£220 0 0	Madras Railway 5 % Stock	340 0 5		
343 0 0	South Indian Railway 4½ % Debenture Stock	509 2 0		
320 0 0	South-Eastern Railway Preferred Ordinary Stock	511 1 0		
				£1,360 3 5
				£8,212 12 2
„ Balance, being amount uninvested at this date, carried to Balance Sheet				208 18 11
				£8,421 11 1

[1] £350 5 % Capital Stock Converted.

"SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount (as per last Account)	2,126	19	3
	£2,126	19	3

"SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Balance (as per last Account)	34	2	1
„ Dividends received in 1900	69	8	4
	£103	10	5

THE "DAVID HUGHES SCHOLAR-

Dr.

	£	s.	d.
To Amount bequeathed by the late Professor David Hughes to form a Scholarship	2,000	0	0
	£2,000	0	0

THE "WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount Presented by Dr. Henry Wilde to form a Benevolent Fund	1,500	0	0
	£1,500	0	0

THE "WILDE BENEVOLENT

Dr.

	£	s.	d.
To Dividends received to 31st Dec., 1900	£21	2	11

FUND" CAPITAL ACCOUNT.

Cr.

		£	s.	d.
By Investments, viz.—				
£1,500 New South Wales 3½ % Stock	...£1,556 5 9			
500 Cape of Good Hope 3½ % Stock	... 570 13 6			
		2,126	19	3
		£2,126	19	3

FUND" INCOME ACCOUNT.

Cr.

	£	s.	d.
By Award for 1900, to Mr. R. P. Howgrave Graham, of the Finsbury Technical College	50	0	0
„ Balance carried forward to Balance Sheet	53	10	5
	£103	10	5

SHIP FUND" CAPITAL ACCOUNT.

Cr.

	£	s.	d.
By Investment £2,045 Staines Reservoirs 3 % Guaranteed Debenture Stock	1,998	15	0
„ Balance uninvested carried to Balance Sheet	1	5	0
	£2,000	0	0

FUND" CAPITAL ACCOUNT.

Cr.

	£	s.	d.
By Investment £875 Great Eastern Railway Metropolitan 5 % Guaranteed Stock	1,493	16	3
„ Balance uninvested carried to Balance Sheet	6	3	9
	£1,500	0	0

FUND" INCOME ACCOUNT.

Cr.

By Balance carried to Balance Sheet £21 2 11

BALANCE SHEET,

Dr.

LIABILITIES.

	£	s.	d.	£	s.	d.
To Life Compositions—Balance uninvested				32	0	0
„ Subscriptions received in advance—						
On Account of 1901	£77	7	8			
„ 1902	4	0	0			
„ 1903	3	0	0			
„ 1904	1	0	0			
				85	7	8
„ "Salomons Scholarship Fund"—Balance of Income Account				53	10	5
„ "Wilde Benevolent Fund"—Balance of Capital uninvested ...	£6	3	9			
„ „ „ „ Balance of Income Account ...	21	2	11			
				27	6	8
„ "David Hughes Scholarship" Fund—Balance of Capital uninvested				1	5	0
„ Building Fund—Balance uninvested				208	18	11
„ Suspense Account—Amount of Subscriptions paid in advance of election				4	8	0
„ General Fund—Balance as per last Account ...	£4,714	4	9			
Add Further Amount received for Photographs connected with the Swiss Visit of 1899	1	19	1			
Estimated Value of Books presented ...	38	15	0			
Excess of Receipts over Expenditure ...	1,549	6	4			
	6,304	5	2			
Less Amount transferred to Building Fund ...	729	11	10			
				5,574	13	4
„ Sundry Creditors				125	15	10
				£6,113	5	10

WALTER G. McMILLAN,
Secretary.

We have examined the Books, Vouchers, and Bankers' Certificates as to the Securities of the Institution, and certify that the above Statements of Account and Balance Sheet are correct, and exhibit the true financial condition of the Institution.

ALLEN BIGGS & CO.,
Chartered Accountants,
38, PARLIAMENT STREET, S.W.

30*th April*, 1901.

Cr.

ASSETS.

		£ s. d.
By Investments, "General Fund"—		
£1,418 8 0 Midland Railway 2½% Consolidated Perpetual Preference Stock	£1,200 0 0	
918 3 2 India 3½% Stock	973 17 10	
10 13 8 Great Indian Peninsula Railway "B" Annuity[1]	274 8 9	
721 0 0 Madras Railway 5% Stock	1,114 14 0	
		3,563 0 7
" Furniture Account (as per last Balance Sheet)	239 3 6	
Add Card Catalogue Cabinet	2 17 0	
		242 0 6
" Stock in hand of Institution Journals, Ronald's Catalogues, &c.—		
As per last Balance Sheet	309 13 3	
Add Cost of Additions in 1900	62 10 0	
	372 3 3	
Less Amount realised during the year ...	129 5 6	
		242 17 9
" Stock in hand of "Cooke's Manuscripts"		18 5 2
" Books, Pictures, &c., other than the Ronald's Library (as per last Balance Sheet)	1,336 19 7	
Add Value of Books and Periodicals since purchased, and Cost of Binding	21 18 10	
Value of Books and Periodicals Presented	38 15 0	
		1,397 13 5
" Stock of Vellum Diploma Forms		3 19 10
" National Telephone Co. Deposit...		0 10 0
" Sundry Debtors for Advertisements in the Journal, &c.		97 19 3
" Local Sections—		
Balance in hands of Hon Secretary, Dublin Section	£0 11 1	
Do., Newcastle Section...	5 19 7	
Do., Manchester Section	1 18 3	
Do., Glasgow Section	0 19 1	
		9 8 0
" Cash Balances at Bankers'—General Account ...	£456 2 11	
Swiss Visit Account	19 4 8	
Petty Cash Account	62 3 9	
		537 11 4
		£6,113 5 10

In addition to the above balances there is an amount of £180 3s. 8d. at the Bank to the credit of the Institution, which has to be accounted for to the guarantors in respect of the Annual Dinner and the American visit.

F. C. DANVERS }
E. GARCKE } *Honorary Auditors.*

[1] £160 5% Capital Stock Converted.

The PRESIDENT: I now beg to move "That the Statement of Accounts and Balance Sheet for the year ending December 31st, 1900, as presented, be received and adopted."

Mr. LEACH: I have very much pleasure in seconding that motion.

Professor SILVANUS THOMPSON: Might we be told from the Chair what steps are being taken towards the realisation of our hopes to have a house of our own? We know the accommodation we have is too small, and our library is growing and ought to be better accommodated. The question is, Are we any nearer the goal?

The PRESIDENT: I may answer that at once. We are about £1,000 nearer the goal. Your President and a number of Members of Council have interested themselves a great deal in this matter, and some five or six months ago we visited a great number of sites. I wish that ten or fifteen years ago there had been a little more activity shown when the sites were cheaper. We need about 10,000 square feet, and as far as I can make out we must pay £3 10s. or £4 a square foot in Westminster. It is beyond our means at the present moment unless Sir Henry Mance or some other financier will undertake to begin with a sum of eight or nine thousand pounds when the capital needed is sixty or seventy thousand. We are all discoverers; if one of us would only discover a Mr. Carnegie interested in electrical things who could give us the money we need, I would at once make an experiment on his generosity. I will now put the resolution to the meeting.

The resolution was carried unanimously.

Professor SILVANUS THOMPSON: We are not, sir, in the position, unfortunately, of meeting in our own hall. If we were in that position, the motion which I rise to move would be entirely unnecessary; but having no hall of our own, we can at any rate enjoy the hospitality of those other Societies which have halls, and as most of our meetings are held in the Hall of the Institution of Civil Engineers, we certainly cannot do less than give to that body our most cordial thanks for the hospitality which it extends to us. What we should have done in past years without the opportunity of using that exceedingly excellent meeting place I do not know. The motion I have to propose is "That the Members of the Institution of Electrical Engineers hereby tender their cordial thanks to the President, Council, and Members of the Institution of Civil Engineers for their generous hospitality in permitting the meetings of this Institution in their building."

Mr. R. P. SELLON: I do not think I need add anything to what Dr. Thompson has said. I feel sure we are deeply sensible of our good fortune in having the theatre of the Institution of Civil Engineers in which to conduct our proceedings, and that we are unanimous in our appreciation of the kindness and courtesy of the Civil Engineers in placing their building at our disposal. I have pleasure in seconding the motion.

The motion was unanimously carried.

Mr. C. P. SPARKS: I beg to propose "That the Members of this Institution express hereby their sincere thanks to the President, Council, and Members of the Institution of Mechanical Engineers and

to those of the Society of Arts for their kindness in allowing this Institution to hold meetings in their respective buildings."

Mr. W. M. MORDEY: I have great pleasure, not unmixed with pain, in seconding the resolution. I feel that it is rather a painful thing that we, a large, prosperous, and comparatively wealthy body, should be lodgers and not householders. That does not, of course, in any way lessen our feelings of gratitude to the Societies who are good enough to grant us the use of their halls, and the facilities we enjoy here and at the Mechanical Engineers.

Mr. P. V. LUKE: We all know how much the prosperity and extension of this Institution is in the hands of our Local Honorary Secretaries and Treasurers; and the large accession of members during the past year, as well as the interesting papers and discussions we have had, is evidence of how well those gentlemen have worked on our behalf. Our greatest field for future extension is probably in the spheres of influence of our honorary secretaries, and it is to them we look in great measure to popularise the Institution and to extend its interests. I understand that there are one or two gentlemen who represent us abroad present to-night, amongst them being Mr. G. G. Ward, of America, and we shall have an opportunity of thanking them personally for their efforts. I beg to propose "That the thanks of the Institution be given to the Local Honorary Secretaries and Treasurers for their services during the past year."

Mr. COOPER seconded the motion, which was unanimously carried.

Mr. GEO. G. WARD, in reply: It is somewhat of a surprise to me to be called upon to speak this evening. At the same time, it is a pleasure to be here to acknowledge this vote of thanks to the Local Honorary Secretaries and Treasurers. I believe every Local Secretary feels it an honour to represent the Institution. I have been Secretary for the United States, I think, since 1876, and I consider it a privilege to be associated with it. I beg to thank you, gentlemen, on the part of my colleagues, and to assure you of my own appreciation of your vote of thanks. You may rely upon my continuing to further the interests of the Institution in every possible way.

The PRESIDENT: I am very glad to think that a Local Honorary Secretary has had a chance of knowing that we do give these yearly thanks. I do not think that the vote is formally sent to them in a letter. There are several of us who have acted as Local Honorary Secretaries. I myself when I was in Japan little knew that these thanks were piling up every year for what one was doing.

Mr. JOHN GAVEY: An eminent engineer was on one occasion asked which was the most difficult engineering problem he had had to face, and he is stated to have said, in reply, the raising of money. Now, whether we agree with that view or not—and many of us will feel inclined to agree with such a statement—it is quite obvious that the money having been raised, the next thing is to provide for its safe custody, and its judicious expenditure. I feel that all of us, as members of this Institution, owe a deep debt of gratitude to the gentlemen who undertake for us the custody of the purse strings, and it is therefore with very great pleasure I propose "That the thanks of this

Institution be accorded to Professor Ayrton for his kind services as Honorary Treasurer during the past twelve months."

Mr. CAMPBELL SWINTON: I think I cannot add anything to what Mr. Gavey has said. Professor Ayrton's energetic temperament is well known to you, and I am sure that anything he undertakes he does with all his heart. I have much pleasure in seconding the resolution.

The resolution was carried unanimously.

Sir HENRY MANCE: I have much pleasure in proposing "That the thanks of this Institution be given to Mr. F. C. Danvers and Mr. E. Garcke for their kind services as Honorary Auditors during the past year." As one of the oldest members of the Institution it has given me much pleasure to see the name of Mr. Danvers occur in our Reports year after year, and in the active association of Mr. Garcke with us we know we have a gentleman most intimately connected with electrical engineering, and whose services are sure to be valuable both as auditor and in other ways.

Mr. A. J. LAWSON: I beg to second Sir Henry Mance's proposal, and I can add nothing to what he has said except that I am sure it is a pleasure to Mr. Danvers and Mr. Garcke to act for the benefit of this Institution.

The resolution was unanimously carried.

Mr. S. Z. DE FERRANTI: I have to propose "That the best thanks of the Institution be tendered to Messrs. Wilson, Bristows, and Carpmael for their kind services as Honorary Solicitors during the past year."

Mr. J. E. KINGSBURY: I have pleasure in seconding that motion, and if I may second it with a few more words than Mr. Ferranti proposed it, I shall be glad if you will allow me to do so. A good many years ago it was my lot to be involved in some legal questions under circumstances in which a lawyer might certainly, if he had liked, have made me a profitable client. I was always brought up with the idea that a lawyer regarded mainly his own interests, but I was introduced to a lawyer who dispelled that idea from my mind entirely. It was the late Mr. Carpmael, of the firm of Wilson, Bristows, and Carpmael, the solicitors to this Institution. I have pleasure in bearing testimony to the advice they were able to give me in my own interests, and from a monetary point of view certainly against their own. In the case of the Institution, since they act as Honorary Solicitors, the question of money does not come in. The Institution is fortunate in having Honorary Solicitors, but I think it is especially fortunate in having such Solicitors as Messrs. Wilson, Bristows, and Carpmael, of whose devotion to the interests of their clients I can speak from experience, and whose identification with electrical affairs is of such long standing, as shown by the fact that they are the successors of the firm who acted for Mr. Cook in reference to his original telegraph patent.

The resolution was agreed to unanimously.

The PRESIDENT announced that the scrutineers reported the following to have been duly elected :—

Members:

Henry Bevis.
Paul Brühl.
Maurice Deacon.
Robert Shedden Dobbie.
Robert Tyndall Gibbs.
Harry Smith Styan.
William Mundell Thornton.

Associate Members:

James Richard Berry.
Ernest Albert Browning.
Henry Davidson.
Edwin Freund.
Edwin Ernest Fuller.
Frederick Mackenzie Lea.
Donald Robert McLagan.
Joseph Platt.
Harry Richardson.
Charles Lionel Ernest Stewart.
Francis Allan Wilkinson.

Associates:

Joachim Henry Adam.
George Herbert A. Armstrong.
Thomas Henry Bacon.
Edwin David Bevenne-Miller.
William James Bishop.
James Frederick Carter.
G. F. St. Clair Harden.
William Henry Herod.
Stephen Kirkwood.
Francis John Lamb.
Victor Mamelsdorf.
Sidney Benjamin Marshall.
Frank William Money.
Frederick Michell Nicholl.
John Macdougall Pollock.
John Moffat Robb.
Fred Sells.
Percy J. Sims.
William Charles Smart.
Anthony R. Vanderveen.
Walter Septimus Vaughton.
E. Counsel Wansbrough.
Sidney David White.
Reginald St. Chad Young.

Students:

Sidney Frazer Barclay.
Henry Thos. George Edmonds.
Joseph D. Griffin.
Cyril John Hopkins.
Percy William Kelsey.
George Louis Kirkpatrick.
William Bell Marr.
William Francis Pepper.
William Trevor Roper.
Thomas Yeo Sherwell, Junr.
Herbert Ashlin Skelton.
Arthur Stanley Wilson.

The PRESIDENT: I have also to announce the result of the election of the new Council for 1901–2. The election is now complete, because under our Articles of Association, as no candidates have been nominated other than those nominated by the Council, the Council's nominees are duly elected :—

President.

W. E. LANGDON.

Vice-Presidents.

R. KAYE GRAY.
Major P. CARDEW, R.E.
S. Z. DE FERRANTI.
JOHN GAVEY.

Institution be accorded to Professor Ayrton for his kind services as Honorary Treasurer during the past twelve months."

Mr. CAMPBELL SWINTON: I think I cannot add anything to what Mr. Gavey has said. Professor Ayrton's energetic temperament is well known to you, and I am sure that anything he undertakes he does with all his heart. I have much pleasure in seconding the resolution.

The resolution was carried unanimously.

Sir HENRY MANCE: I have much pleasure in proposing "That the thanks of this Institution be given to Mr. F. C. Danvers and Mr. E. Garcke for their kind services as Honorary Auditors during the past year." As one of the oldest members of the Institution it has given me much pleasure to see the name of Mr. Danvers occur in our Reports year after year, and in the active association of Mr. Garcke with us we know we have a gentleman most intimately connected with electrical engineering, and whose services are sure to be valuable both as auditor and in other ways.

Mr. A. J. LAWSON: I beg to second Sir Henry Mance's proposal, and I can add nothing to what he has said except that I am sure it is a pleasure to Mr. Danvers and Mr. Garcke to act for the benefit of this Institution.

The resolution was unanimously carried.

Mr. S. Z. DE FERRANTI: I have to propose "That the best thanks of the Institution be tendered to Messrs. Wilson, Bristows, and Carpmael for their kind services as Honorary Solicitors during the past year."

Mr. J. E. KINGSBURY: I have pleasure in seconding that motion, and if I may second it with a few more words than Mr. Ferranti proposed it, I shall be glad if you will allow me to do so. A good many years ago it was my lot to be involved in some legal questions under circumstances in which a lawyer might certainly, if he had liked, have made me a profitable client. I was always brought up with the idea that a lawyer regarded mainly his own interests, but I was introduced to a lawyer who dispelled that idea from my mind entirely. It was the late Mr. Carpmael, of the firm of Wilson, Bristows, and Carpmael, the solicitors to this Institution. I have pleasure in bearing testimony to the advice they were able to give me in my own interests, and from a monetary point of view certainly against their own. In the case of the Institution, since they act as Honorary Solicitors, the question of money does not come in. The Institution is fortunate in having Honorary Solicitors, but I think it is especially fortunate in having such Solicitors as Messrs. Wilson, Bristows, and Carpmael, of whose devotion to the interests of their clients I can speak from experience, and whose identification with electrical affairs is of such long standing, as shown by the fact that they are the successors of the firm who acted for Mr. Cook in reference to his original telegraph patent.

The resolution was agreed to unanimously.

The PRESIDENT announced that the scrutineers reported the following to have been duly elected :—

Members:

Henry Bevis.
Paul Brühl.
Maurice Deacon.
Robert Shedden Dobbie.
Robert Tyndall Gibbs.
Harry Smith Styan.
William Mundell Thornton.

Associate Members:

James Richard Berry.
Ernest Albert Browning.
Henry Davidson.
Edwin Freund.
Edwin Ernest Fuller.
Frederick Mackenzie Lea.
Donald Robert McLagan.
Joseph Platt.
Harry Richardson.
Charles Lionel Ernest Stewart.
Francis Allan Wilkinson.

Associates:

Joachim Henry Adam.
George Herbert A. Armstrong.
Thomas Henry Bacon.
Edwin David Bevenne-Miller.
William James Bishop.
James Frederick Carter.
G. F. St. Clair Harden.
William Henry Herod.
Stephen Kirkwood.
Francis John Lamb.
Victor Mamelsdorf.
Sidney Benjamin Marshall.
Frank William Money.
Frederick Michell Nicholl.
John Macdougall Pollock.
John Moffat Robb.
Fred Sells.
Percy J. Sims.
William Charles Smart.
Anthony R. Vanderveen.
Walter Septimus Vaughton.
E. Counsel Wansbrough.
Sidney David White.
Reginald St. Chad Young.

Students:

Sidney Frazer Barclay.
Henry Thos. George Edmonds.
Joseph D. Griffin.
Cyril John Hopkins.
Percy William Kelsey.
George Louis Kirkpatrick.
William Bell Marr.
William Francis Pepper.
William Trevor Roper.
Thomas Yeo Sherwell, Junr.
Herbert Ashlin Skelton.
Arthur Stanley Wilson.

The PRESIDENT: I have also to announce the result of the election of the new Council for 1901–2. The election is now complete, because under our Articles of Association, as no candidates have been nominated other than those nominated by the Council, the Council's nominees are duly elected:—

President.

W. E. LANGDON.

Vice-Presidents.

R. KAYE GRAY.
Major P. CARDEW, R.E.
S. Z. DE FERRANTI.
JOHN GAVEY.

Members of Council.

H. H. Cunynghame, C.B.	A. J. Lawson.
H. Edmunds.	The Hon. C. A. Parsons, F.R.S.
Robert Hammond.	W. H. Patchell.
H. E. Harrison, B.Sc.	J. H. Rider.
Hugo Hirst.	Mark Robinson.
Lieut.-Col. H. C. L. Holden, R.A., F.R.S.	R. P. Sellon.
	C. P. Sparks.
J. E. Kingsbury.	James Swinburne.

Associate Members of Council.

W. R. Cooper, M.A., B.Sc. | W. Duddell.
R. W. Wallace, K.C.

Honorary Auditors.

Frederick C. Danvers. | E. Garcke.

Honorary Treasurer.

Professor W. E. Ayrton, F.R.S., Past-President.

Honorary Solicitors.

Messrs. Wilson, Bristows, & Carpmael, 1, Copthall Buildings, E.C.

Prof. J. Perry: You have now, gentlemen, elected Mr. Langdon as my successor, and he is about to take the chair at this meeting. It would have been a very easy thing for me to prepare a long speech about Mr. Langdon, stating the nature, or something of the nature, of the services he has rendered to the electrical industry, and of the papers he has read before our Institution, many of them when some of the members present were in long clothes. But what is the use of my making a speech about Mr. Langdon? You have elected him President of the Institution with your eyes perfectly open, and I take it you must know quite as much about him as I should be able to say in the short time at my disposal. I will, therefore, without any further words, ask Mr. Langdon to take the chair.

Professor Perry then vacated the chair, into which he inducted Mr. Langdon.

The President (Mr. Langdon): I beg to tender you, gentlemen, my most hearty thanks for the honour you have conferred upon me. I associate with that honour a desire on your part to recognise the services of that branch of our Institution which I may perhaps lay claim to have represented on the Council. I think, also, I may perhaps go a little beyond this and tender you thanks for a desire on your part to confer honour on one who has spent a good many, although perhaps not so many years as Professor Perry has suggested, in telegraph work, and in seeking to further the advancement of electricity on railways. On behalf of those whom I may assume to represent, as also on my own behalf, I tender you my most hearty thanks.

I shall enter on my duties with a very great deal of diffidence, but

of this I feel assured, that, in appealing to you for your assistance and support, and for your confidence, in the discharge of those duties, I shall not appeal in vain. I feel that you will grant to me the same support and afford me the same confidence you have so generously accorded my predecessors. I readily assure you that my every effort shall be to deal with the duties devolving upon me to the utmost of my power, and in the best interests of the Institution. If it should be that I am not able to perform those duties to my own satisfaction, or to that of my colleagues, I shall promptly return into your hands the trust with which you have invested me. I thank you, gentlemen, very heartily for the kind manner in which you have received my remarks.

Mr. R. K. GRAY: I think I am expressing the feeling of all present in tendering to the retiring President, Professor Perry, our very best thanks for the manner in which he has conducted the affairs of this Institution during his period of office. The Report you have just heard tells the story, and you can gather from it the amount of work which Professor Perry must have done in the session just closed; but in addition to the work recited in the Report, we must remember that last year was no common year. We had our American cousins with us, and Professor Perry, with that genial manner of his, certainly captivated our visitors, and represented this Institution as it should be represented. We went under his presidency to Paris to be present at the joint-meeting of our Institution and of the Institution of Electrical Engineers of America, and there, with his American colleague, Dr. Hering, Professor Perry was tireless in doing everything that could be done to make the joint-meeting an undoubted success. It is needless for me to say, gentlemen, in your presence, how much we esteem our past President, and how sorry we shall be to miss his kindly face in the chair. I have much pleasure in proposing "That the cordial thanks of the Institution of Electrical Engineers be offered to Professor Perry for the self-denying zeal and energy that he has shown whilst filling the office of President, and for the constant care he has devoted to the interests of the Institution and to the duties of his office."

Mr. R. W. WALLACE, K.C.: I assume that the reason I am asked to second this resolution is that I am not by profession an electrical engineer. You have heard to-night, when Messrs. Wilson, Bristow, and Carpmell were being spoken of, the category in which lawyers are placed. However, I cannot claim, like them, to be an exception to the rule. But although you may be a wicked lawyer, that is no reason why you should not approve the good in others, and especially in your President. With regard to the object of this vote, I think every member of the Institution of Electrical Engineers will be at one with me in thinking that there has never been a better President than Professor Perry. You have heard of his geniality. I do not know the number of times he must have been in Paris, but I remember he was there once with me as a co-delegate on behalf of this Society to some other societies, and I can tell you the President was very gay, and did his duty extremely well. But there is a very serious side to the work of this Institution, and since last I was an Associate Member of Council, —it must be eight or ten years ago now—I notice that the work of the

Society has about doubled, and that the share of it to be got through by the President is something phenomenal. This means giving up a great deal of valuable time; and on the other hand, when we consider that Professor Perry has had to adjudicate, as he says, somewhat autocratically sometimes, on very vital questions affecting the Institution, in a very few minutes before the papers are read, and has been able to do so with much geniality, I have no doubt you will see that you are much indebted to him for the services he has rendered during the past year. I hope he may be long spared to smile at us, and perhaps at some other time to take the chair. It is a very difficult thing in a new Institution like this to find excellent men every year, and how you have been able to do it up to the present is wonderful. Yet, it would not do for Presidents to have the work they have to do for more than one year in succession, because I am certain it would involve too great a sacrifice.

The resolution was carried with acclamation.

Professor Perry, in responding, said: It must give you, sir, a great deal of confidence in beginning your year's work when you think that your services in the chair will be acknowledged in this sort of way at the end of your year of office. It is not much that one does, after all, to get the gratitude of an important Institution like this. I thank Mr. Gray and Mr. Wallace very much for the way in which they have spoken about me. There is no doubt about it, it has been a very hard year, and the attendance on all those Committees has been a pretty heavy job considering the other work one has to do. But then you must remember that probably I took the business just a little too seriously. I think that if I had attended about one-third of the Committee meetings, and left out an occasional Council meeting or ordinary meeting, the Institution might have been just as comfortable and perhaps even more good-humoured with me. But I had such an inclination to have my finger in every pie, that I am afraid the Secretary and others must have sometimes thought I was a bit of a nuisance. To give you an example of the sort of thing I mean. You remember the American river-trip. Before that river-trip I was sleepless for nights. I felt sure there would be a hitch about the electric launches, or the luncheon, or something else. I could foresee no end of things that might happen to bring disaster and disgrace upon the Institution. The time came—preparations had to be made—and Mr. McMillan quietly took the whole thing into his hands, with all its details, and he pulled it through without a hitch of any kind, and he did not turn a hair. This was a lesson to me. Afterwards I simply left Mr. McMillan to do the work. We went to Paris and had no end of fuss there in all sorts of ways; we had our Annual Dinner; and we also received the South African Contingent—and I did not turn a hair. I knew it would all come right. Mr. McMillan gave me his orders: Stand so; try to convert your grin into an amiable smile; go to Covent Garden Opera House at such and such a time, and I obeyed him. What I did was necessary and formal and proper, and I got the credit, but he was the man who did the work. But there is a serious side to this power of Mr. McMillan to take up all sorts of work and pull it through. We are taking too much work out of Mr. McMillan.

There is a great deal too much output, and I am sorry to say it is an output with too big a load factor. There is no interval of rest almost in the 24 hours. Until you become President of the Institution you cannot really know how much work Mr. McMillan is doing. I give him my personal thanks, and as past President of the Institution I give him the thanks of the Institution for what he has done. I should also like to say that I give my thanks to the Members of Council ; more earnest, considerate, sympathetic, hard-working Members of Council I cannot possibly imagine, faithfully attending Committee meetings, and helping the President in every possible way. I am glad the year is over ; there is no doubt about that, for many reasons and for one in especial, namely, because I seem to have a native talent for "putting my foot in it" whenever it is possible to do so. On several occasions I know I have put my foot in it rather sadly. I know the Members of Council have forgiven me for any mistakes I have made, but there is this to be said : eighteen months ago I am certain that I was on absolutely friendly terms with every member of this Institution, whereas I am sorry to think that now it is just possible that two or three members of this Institution may feel that they have a right to be a little annoyed with me. I can only say it was merely zeal, and that I did everything for the best. I did not in any way want to hurt anybody's feelings.

I thank you again, gentlemen, for the way in which you have received this resolution.

OBITUARY NOTICES.

EDWARD HENRY BOLD, who died on the 4th of May, 1900, was born at Clitheroe in Lancashire in 1841, and worked first at mechanical engineering in the workshops of Messrs. Bridge and Barnes, and then in the chemical laboratory of Mr. John Sieber. He sailed for Australia in 1861, and, on his arrival, became assistant to Mr. Richard Millet, a civil engineer in Melbourne. He afterwards, in 1863, settled in New Zealand, and was engaged, first in road-construction and then in mining, under the Provincial Government of Canterbury. Then, in 1867, Mr. Bold accepted the position of Telegraph Engineer, and was employed in superintending the construction of the line from Wellington to Auckland. In 1868 he successfully carried a line, in part through native territory, to Oruanini, having been given power to treat with the natives, many of whom were so hostile that the work of construction had to be carried on under the protection of an armed constabulary. This work involved the cutting of a road through the centre of the North Island; and Mr. Bold afterwards became Road Engineer for Taupo and the East Coast, under the newly-formed Public Works Department, from which he was retired in 1878. Dr. Lemon, who has since followed his late assistant, wrote concerning him that he excelled as an electrician, and had accompanied him (Dr. Lemon) as his right-hand man in all his cable-repairing expeditions.

Mr. Bold was elected a Member of the Institution of Electrical Engineers on December 10th, 1879.

GEORGE FRANCIS FITZGERALD was born in 1851 at the old Rectory, Kill-o'-the-Grange, Monkstown, Co. Dublin, of which parish his father, afterwards successively Bishop of Cork and Killaloe, was then rector. His education was a home one under tutor until he entered Trinity College, Dublin, at the age of sixteen, in 1867. His undergraduate course in the University was a most distinguished one, he taking the highest place in Mathematics and Experimental Science at his degree in 1871. He gained a Fellowship in 1877, and in 1881 was appointed the Erasmus Smith Professor of Natural Philosophy, which post he held for the rest of his life. He was elected a Fellow of the Royal Society in 1883, and in 1899 he had conferred upon him one of the Society's Royal Medals. He was made an Honorary Fellow of the Royal Society, Edinburgh, in 1900.

Up to his appointment to the Professorship there had been no teaching in Dublin in Practical Physics, but on his obtaining possession of an old disused chemical laboratory he started classes in Experimental Physics, and shortly gathered round him earnest workers in that branch of science. He ever had at heart the claims of experimental science in his University, and though he succeeded in effecting considerable advances, it remained to the end a source of disappointment to him that he could not move the authorities to bring things up to the requirements of the day.

Fitzgerald was early impressed in electrical matters with Maxwell's

views, then new and imperfectly understood by the scientific world, and actively introduced them into his teaching. He published in 1876 his first paper on the "Rotation of the Plane of Polarisation of Light by Reflection from the Pole of a Magnet," and in 1880 his paper on the "Electro-magnetic Theory of Reflection and Refraction of Light," in which he showed how the relations established in the older theories were in agreement with Mawell's "Electro-magnetic Theory of Light" and afforded it signal support. From that time he continuously interested himself in this subject, and in the possibility of obtaining by electro-magnetic means Maxwellian Radiation.

Many of his papers to the Royal Dublin Society and elsewhere elucidated this question, and he succeeded in devising means, the only one still available, for producing these electro-magnetic waves. He was deterred from making practical application of them by not seeing at the time how the presence of these waves might be detected. He thus was prepared for and warmly welcomed the announcement of Hertz's achievements in electro-magnetic radiation, and brought these discoveries prominently before the English scientific world in his address to the Mathematical and Physical Section of the British Association in Bath in 1888, and later in a lecture at the Royal Institution. Both these discourses were rich in pregnant ideas and suggestions which helped on and inspired in no small degree the great body of work which was shortly to put our knowledge of electro-magnetic radiations into the position of being available for practical applications.

In 1885 he invented and constructed a model illustrating Maxwell's theory of electric and magnetic displacement which was of considerable influence in meeting the objections then often urged that the ether postulated was unmechanical.

He published in 1879 a paper on "Vapour Pressure near Curved Liquid Surfaces," in which he gave an explanation based on molecular considerations of the well-known relations established earlier by Lord Kelvin from thermo-dynamics. He contributed important papers on numerous other questions to various scientific societies which are to be found in their publications.

His mind was of an eminently practical type, and had his life been one thrown more in immediate contact with the pressing problems of engineering, would doubtless have produced much fruit in inventive applications of science.

For many years he took an active part in general educational matters, both in his own University and elsewhere. To his assistance was largely due the inauguration in Ireland of technical education, and the founding in Dublin in 1887 of the Kevin Street Technical Schools, in which he continued until his death to take an active interest.

He was a Member of the Board of National Education for Ireland, and to him in great measure must be attributed the improvements of late introduced into the system of primary education. He was a member of the recently created Board of Technical Instruction for Ireland, to which he was able to give, on its inception, important guidance through his extensive knowledge of the subject. He was also a member of the Board of Intermediate Education.

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His friends felt for some time that all this work for the public weal, when added to his scientific and professional duties, was growing beyond his powers of physical endurance. It no doubt tended to aggravate during the last year the digestive disorders he was subject to, and to which he succumbed at the comparatively early age of forty-nine. He passed away at a time when his great knowledge and matured judgment were being fully appreciated, and when his attainments were being freely utilised for the benefit of his country.

Fitzgerald was himself a most enthusiastic teacher, and his pupils ever felt, even in the most commonplace subjects, that they were being carried along with him in paths leading to new realms of knowledge.

His judgment and advice on matters relating to scientific research were widely appreciated. This entailed an ever-increasing correspondence which he ungrudgingly maintained, giving help to other workers in science, the results of which it would be hard to over-estimate.

His acquaintance with what had been already done in science was extensive. This, with his own inventive skill, was always at the disposal of those seeking his assistance.

At scientific gatherings and discussions he stood out pre-eminent through a power of rapidly grasping the essential, and few subjects arose on such occasions to which he did not add interest from his clear penetrating vision.

His presence was always a welcome one among his friends, and ever carried with it a feeling and influence of an elevating nature. It is given to few men to leave with their very intimates a memory, as it were, of a superior being, such did he.

Professor Fitzgerald was President of the Physical Society of London in 1892. He was elected a Member of the Institution of Electrical Engineers on the 10th of December, 1891. On the formation of the Dublin Local Section in 1899 he was elected first Chairman of the Section, and his inaugural address in that capacity was printed in the Journal of the Institution in 1900.

F. S. T.

CHARLES EDWARD GROVE was born on the 10th of March, 1863, in Limehouse, and, commencing his career as an office-boy, by indomitable perseverance and industry combined with unusual talents, succeeded after office hours in obtaining the education which assisted him so greatly in after years. In 1879 he became a Lower Division Clerk in the Post Office, and in that and succeeding years carried off many prizes at the City of London College and the Birkbeck Institution, including the Thompson Prize in 1882, and the Lubbock Scholarship in 1883. In 1884 he gained the prize given by the Saddlers' Guild for Applied Mechanics, and, besides studying himself, was engaged for about eight hours a week in teaching. In 1887 he undertook an examinership in Applied Mechanics, and was transferred to the office of the Engineer-in-Chief at the Post Office, where he served under Mr. Graves. He was specially selected to deal with the Pneumatic Telegram System of the General Post Office, and wrote the Technical Instructions on the system officially supplied to the staff. He also

designed and superintended the erection of the machinery employed for the installations at Grimsby and Bradford. In 1887 he obtained the City and Guilds silver medal and first prize in Electric Lighting, in 1889 the silver medal for Telegraphy, and in 1892 the silver medal and first prize for Telephony.

In 1892 he left the service of the Post Office and took charge of the newly-formed Electrical Engineering Department of the Thames Ironworks and of the Company's science classes. He remained at the head of this department to the time of his death, which occurred on January 11th, 1901, as the result of typhoid fever. His intense devotion to his work, his enthusiasm, his ability, and his thoroughness, combined with the great amiability of his character, have caused his loss to be felt very keenly by all those with whom he had been brought into touch.

Mr. Grove was elected an Associate of the Institution of Electrical Engineers on the 26th of April, 1888, and was transferred to the class of Members on the 22nd of April, 1897. In 1900, he read a paper before the Institution (published in this Journal, 1900, **29**, 530) on the "Electrical Equipment of Ships of War," for which he was awarded the Institution Premium.

(*Abstracted, in part, from a memoir in the Thames Ironworks Gazette.*)

CHARLES LEMON, who died on the 6th of May, 1901, at Otaki, New Zealand, in his sixty-seventh year, was educated, in part, in the Technical College at Kennington, London. Proceeding to New Zealand, he joined the Postal Service, becoming General Manager of Telegraphs in 1867, and, in 1881, Superintendent of the Postal and Telegraph Department. Under his supervision the department grew enormously, and his policy of reducing the rates for the transmission of telegraphs, although opposed initially, proved itself abundantly successful.

In recognition of the assistance given by him to the astronomers who visited New Zealand to make observations in connection with the transit of Venus, he was admitted to the Honorary Degree of Doctor of Philosophy by the Hamilton University in the United States.

Dr. Lemon was elected a Member of the Institution of Electrical Engineers on the 11th of December, 1872. From 1883 to the time of his death he was the Local Honorary Secretary and Treasurer of the Institution for New Zealand. In 1874 he wrote a paper on "Duplex Telegraphy in New Zealand," which was published as an Original Communication in the Journal (1874, **3**, 487).

E. W. PARSONÉ was educated at University College School. His connection with submarine telegraphy commenced in 1870, when, under the late Sir Charles Bright, he was engaged on the electrical staff during the laying of the first West Indian cables. Subsequently, as electrician and engineer, he was employed by the India Rubber, Gutta Percha and Telegraph Works Company, and took part, among other work, in the connecting by submarine cables of various points along the French Atlantic Coast, the laying of cables in the Mediteranean between France and Algeria and between Marseilles and Barcelona, the laying of cables

for the West Coast of America Telegraph Company between Peru and Chile, the survey in S.S. *Retriever* of the routes for cables laid along the Pacific Coast of South and Central America for the Central and South American Telegraph Company, and various surveys and cable operations on the West African Coast.

It was apart, however, from the purely technical portion of submarine cable work that Mr. Parsoné was, perhaps, better known in the telegraphic world. As manager of the West Coast of America Telegraph Company, then of the West African Telegraph Company, and, at the time of his death, of the South American Cable Company, his energy, his business abilities, his intimate knowledge of the various conditions and requirements, commercial and technical, present in the management and administration of telegraphic communications, were conspicuous. His tact and readiness of resource were notable during the war between Peru and Chile, when, under very trying circumstances, he succeeded in steering his Company through the many difficulties inevitable where cables touched at ports alternately in the possession of one or other of the belligerents; his *savoir faire* during this anxious period was evidenced by the many and lasting friendships he made among both Peruvian and Chilian officials, and among the merchants on the coast.

He received from the French Government the decoration of Officier de l'Instruction Publique for his services in facilitating astronomical observations and in the determination of positions on the West Coast of South America; and the Portuguese Government created him a Knight Commander of the Order of Christ for his work in the Portuguese possessions on the West Coast of Africa. He was a Fellow of the Geographical Societies of London and of Lisbon.

The prolonged illness (a complicated affection of heart and liver) from which Mr. Parsoné suffered, the result of long services in tropical climates—an illness which he bore with exemplary patience—terminated at his residence in Leyland Road, Lee, on the morning of the 20th of May, 1901. He was interred in Lee cemetery on the 23rd of May, and the large and sympathetic gathering present at the funeral testified to the esteem in which he was held. Cheery and humorous as a companion, thoughtful and trustworthy as a friend, kindly and considerate towards his subordinates, his loss will be keenly felt not only by those who were his intimates, but by a large circle of fellow workers and acquaintances who had learned to appreciate his many sterling qualities.

Mr. Parsoné was elected an Associate of the Institution of Electrical Engineers on the 26th of November, 1873, and was transferred to the class of Members on the 21st of September, 1881. E. M. W.

H. K. TAVARIA was born in 1865, and matriculated in Bombay University from the St. Xavier's College in 1882, graduating first in Medicine and Surgery and then in Science. In 1893 the City and Guilds of London Institute arranged to hold Technological Examinations in Bombay, and Mr. Tavaria passed in that year in Electrical Engineering, and in the two following years respectively in

Telegraphy and Telephony and in Electro-plating and Deposition. Later, he took a very active part in connection with these examinations in the Victoria Jubilee Technical Institute, Bombay. Mr. Tavaria gave many public lectures, and was the author of a monograph on the Dyeing Industry in India. From 1888 to the time of his death he held the position of Lecturer on Physics at the Victoria Jubilee Technical Institute. As the first lecturer on this subject appointed by the Institute, he was responsible for the organisation of the laboratories and of the work of the Department. Into this work he threw himself energetically, and, in 1891, introduced Electrical Engineering as one of the subjects dealt with in the college. In 1895 Mr. Tavaria travelled for a few months in England and on the Continent, visiting some of the principal engineering works.

He was elected an Associate of the Institution of Electrical Engineers on the 26th of November, 1891, and was transferred to the class of Associate-Members on the 9th of March, 1899.

PHILIP BILLINGSLEY WALKER was the son of the Rev. James B. Walker, for some years Head Master of King's School, Parramatta. He was born at Cheltenham, and proceeding to Australia, was educated at Parramatta. On leaving school he joined the Public Works Department of New South Wales, and was shortly afterwards transferred to the Telegraph Department, in which he rapidly became an expert not only as an electrician but as an operator; he was promoted to the position of Assistant Superintendent under Colonel Cracknell, and on the death of the latter, in 1893, succeeded him, with the designation of Secretary to the Telegraph Service, a designation which was afterwards changed to that of Chief Electrician and Engineer-in-chief of Telegraphs. He was associated with Colonel Cracknell in the formation of the first Torpedo Corps of the Naval Brigade, and took a keen interest in its development. After 42 years of public service, Colonel Walker died, at the age of 61, on the 5th of August, 1900.

Colonel Walker was elected a Member of the Institution of Electrical Engineers on the 13th of January, 1887, and was, in 1893, appointed Local Honorary Secretary and Treasurer of the Institution for New South Wales, a position which he retained until the end.

REFERENCES TO PAPERS READ BEFORE LOCAL SECTIONS OF THE INSTITUTION, AND PUBLISHED IN THE TECHNICAL PRESS, BUT NOT APPEARING IN THE JOURNAL OF THE INSTITUTION.

DUBLIN LOCAL SECTION.

"ELECTRIC CURRENTS OF HIGH TENSION AND GREAT FREQUENCY," by Monsignor G. MOLLOY, D.D., D.Sc., Member.
Electrical Review, Vol. **48,** p. 37, Jan. 4, 1901.

"NOTE ON A HUMMING TELEPHONE," by F. GILL, Member.
Electrical Review, Vol. **48,** p. 951, May 31, 1901.

GLASGOW LOCAL SECTION.

"UTILISATION OF WATER POWER FOR ELECTRICAL PURPOSES," by R. F. YORKE, Member.
Electrical Engineer, Vol. **27,** p. 86, Jan. 18, 1901.
Electrical Review, Vol. **48,** p. 127, Jan. 18, 1901.
Electrician, Vol. **46,** p. 436, Jan. 11, 1901.

"NOTES ON SOME SYSTEMS OF LAYING UNDERGROUND MAINS," by A. DEVEY, Associate.
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Electrician, Vol. **47,** p. 22, April 26, 1901.
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"NOTES ON ELECTRICAL WIRING," by G. A. CLARK, Associate Member.
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Scottish Electrician, Vol. **1,** p. 58, April, 1901.

MANCHESTER LOCAL SECTION.

"DIRECT-CURRENT GENERATORS," by SIDNEY H. SHORT, Member.
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Electrical Review, Vol. **48**, p. 647, April 12, 1901.
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NEWCASTLE LOCAL SECTION.

"METHODS OF INCREASING THE DENSITY FACTOR OF ELECTRICITY WORKS," by C. TURNBULL, Associate Member.
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INDEX TO VOL. XXX.

1900—1901.

Obituary Notices of :—

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